DRYING METHODS AND THEIR EFFECTS ON BIOACTIVE COMPOUNDS AND QUALITY OF GEORGIA BLUEBERRIES

by

LAURA ANN PALLAS

(Under the Direction of William L. Kerr)

ABSTRACT

Blueberries have many suggested health benefits, most attributed to their high antioxidant content. To extend their short shelf life, fresh blueberries are frozen and then further processed. One method of preserving blueberries involves drying to a water activity (a_w) < 0.63. Developing drying methods to optimize the final bioactive compounds content and understanding the impacts of drying on the nutritive and quality aspects are needed to create higher quality dried products. The main objectives were to produce dried whole blueberries (*Vaccinium ashei* Reade) with varying moisture content (MC) and a_w values based on time and temperature combinations and to determine the effects of physical characteristics and processing conditions on the final quality and antioxidant activity in a vacuum belt dryer and jet-tube fluidized bed dryer. Pretreatments included freezing and mechanical abrasion in vacuum belt drying and scarification and sugar infusion in fluidized bed drying. Freezing blueberries prior to vacuum belt drying yielded lower final moisture contents, higher antioxidant activities (H-$ORAC_{FL}$), and improved structural retention compared to drying of refrigerated fresh blueberries. Mechanical abrasion decreased vacuum belt drying time in fresh but not frozen

blueberries. Total phenolics content (TPC) was not impacted by vacuum belt drying or fluidized bed drying while higher temperature and osmotic dehydration reduced total monomeric anthocyanins (TMA). Hydrophilic-oxygen radical absorbance capacity (H-$ORAC_{FL}$) values were maintained or increased at all drying times compared to control values. Continuous vacuum belt drying shows promise for an uninterrupted method of drying blueberries in less time than freeze-drying while maintaining the bioactive activity in the dried product. Jet-tube fluidized bed drying offers a method for rapidly producing high-quality, shelf-stable sweetened and non-sweetened blueberries.

INDEX WORDS: Vacuum Belt Drying, Hot Air Drying, Fluidized Bed Drying, Blueberries, Antioxidant, ORAC, Sensory, Split-split Plot

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DEDICATION

To my parents, Dr. James E. Pallas, Jr. and Betty Y. Pallas

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Some say the experience through the PhD program is a “sink” or “swim” venture with a few swimming further than others, but it’s not the distance or the final destination that really matter. It’s the experiences and the people encountered during our lives that shape who we are and our future. I like to think of the journey through life as having numerous adventures along the way. For me, one of these adventures has been the pursuit of the PhD with a few detours and side excursions. Most certainly, I would not have completed this adventure without the support of family and friends.

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TABLE OF CONTENTS

Page

APPENDICES

LIST OF TABLES

Page

LIST OF FIGURES

Page

CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

1.1 Introduction

The dissertation is organized into six chapters. Chapter 1 contains a review of literature on drying of blueberries, in particular the bioactive compounds in blueberries before and after drying. Chapters 2 thru 5 are presented in the manuscript style, prepared for submission to scientific journals. Drying factors in vacuum belt drying fresh blueberries were assessed to achieve a wide range of moisture content (MC) and water activity (a_w) values in Chapter 2. Chapter 3 contains continued work on drying factors involved in vacuum belt drying blueberries with focus on pretreatment including freezing and the effects on the bioactive compounds due to drying. Chapters 2 and 3 both include the development of statistical programs to analyze the split-split plot designs. These programs and their outputs have been placed into Appendices A thru E. The fourth and fifth chapters involve drying blueberries in Alma, Georgia in a JetZone fluidized bed dryer. Chapter 4 studies the effects of drying temperature on the retention of bioactive compounds, moisture properties, and sensory of Georgia blueberries. In Chapter 5, five cultivars of Georgia rabbiteye blueberries were dried and their resulting moisture properties, color, sensory and phytochemical retention were measured for better understanding differences amongst cultivars when subjected to similar drying conditions. Significant findings are summarized in Chapter 6, along with suggestions for further study.

1.2 Blueberries Overview

Blueberries, native to North America, are grown around the world. When ripe, they are small bluish-purple round berries about 2.5 cm in diameter. Blueberries have a pH of 3.8-3.9 with a sweet to tart flavor (Stojanovic & Silva, 2007). The characteristic blueberry color is predominantly attributed to anthocyanins which are enclosed in the epidermal and subepidermal cells (Allan-Wojtas et al., 2001). Cultivars vary in susceptibility to pigment bleeding, depending on berry size, cell wall, and epidermal integrity plus the number of pigmented cell layers (Allan-Wojtas et al., 2001). A large central vacuole comprises the majority of the fruit cell interior with a small band of cytoplasm lying between the vacuole and cell wall (Allan-Wojtas et al., 2001).

Blueberries belong to the same genus, *Vaccinium,* as cranberries, bilberries, and lingonberries. Most blueberries cultivated today can be categorized into one of the following groups of interrelated species or a combination thereof: lowbush, *V. angustifolium* Aiton; northern highbush, *V. corymbosum* L.*, V. fuscatum* Aiton*,* and *V. simulatum* Small; and rabbiteye, *V. ashei* (also known as *V. virgatum*) . Lowbush blueberries are native to the northern United States and Canada. They are known for their small berry size with bushes growing low to the ground. Southern highbush blueberry cultivars are crosses between northern highbush (*V. corymbosum*) and native southern species such as *V. darrowii*. Southern highbush blueberries are hybrids of the northern highbush blueberries and bred to withstand fewer cold hours and different climatic conditions of the southern United States. Rabbiteye blueberries, *V. ashei* Reade, are native to the southern United States, in particular south Georgia, southeast Alabama, and north Florida, and have been cultivated with much success beginning in 1887 (Krewer & NeSmith, 2002). In recent years, the most commonly planted rabbiteye cultivars have been ‘Brightwell’, ‘Climax’, ‘Powderblue’, and ‘Premier’ (Krewer & NeSmith, 2002).

1.3 Phytochemicals

Phytochemicals are secondary plant metabolites; many of which are known to protect against oxidative damage and aid in signaling ripeness. These protective metabolites in fruits and vegetables primarily include phenolic compounds, L-ascorbic acid, and carotenoids. Blueberries contain numerous phytochemicals including anthocyanins, proanthocyanidins, flavonols, flavanols, and phenolic acids (de Pascual-Teresa et al., 2000; Naczk & Shahidi, 2006). Their level of production in plants are influenced by genetic factors and environmental conditions (Singh et al., 2003). Many factors including light, temperature, soil type, genetics, and agronomic conditions cause variations in total anthocyanins in plants, leading to differences in phytochemical content between harvest batches and year (Kalt & McDonald, 1996; Lee et al., 2005; Naczk & Shahidi, 2006). An example is the higher anthocyanin content in apples exposed to sunlight than apples ripened in the shade (Awad et al., 2000).

Kalt et al. (2003) found that the anthocyanin content significantly increased with blueberry maturity while total phenolics content and antioxidant capacity decreased with berry maturity. A study by Howard et al. (2003) reported that differences between blueberry cultivars were far greater than seasonal differences for the anthocyanin content, total phenolics content, and antioxidant activity of blueberries.

Phytochemicals have received much attention in recent years due to their antioxidant properties, in particular quenching of reactive oxygen species. Phenolic compounds are recognized by having one or more aromatic rings with attached hydroxy groups; they scavenge free radicals by donating hydrogen atoms from the hydroxy moieties or electrons from oxidizable double bonds and hydroxyl groups (Bohm et al., 2006; Kalt, 2005). The primary phenolics found in blueberries are anthocyanins, flavonols, proanthocyanidins, and

hydroxycinnamates. Other berry phenolics include flavanols, ellagitannins, gallotannins, and phenolic acids (Seeram et al., 2006). Anthocyanins, flavonols, and proanthocyanidins are located mainly in the peel while hydroxycinnamates are found in the flesh (Golding et al., 2001). Proanthocyanidins, also referred to as condensed tannins, are comprised of catechin or epicatechin monomeric units linked together; linkages vary between A- and B-type (Lazarus et al., 1999). The antioxidant mechanisms of phenolics include hydrogen atom donation, electron donation, metal ion chelation, ascorbic acid sparing, and reactive oxygen species quenching (Kalt, 2005). Electrons are donated by conjugated double bonds in carotenoids and by vicinal hydroxy groups in phenolics (Kalt, 2005).

In aqueous acidic solutions, anthocyanins equilibrate into four structures and exhibit a color based on the combined concentration of these structures: flavylium cation which is red, quinoidal base which is blue, carbinol pseudobase which is colorless, and chalcone which is light yellow to colorless (Wojdylo et al., 2009). Anthocyanins identified in blueberries include cyanidin, delphinidin, malvidin, peonidin, and petunidin with sugar moieties of glucose, galactose, and arabinose (Gao & Mazza, 1994). The blue, red, and purple pigments in blueberries are glycosides of delphinidin, cyanidin, and pelargonidin, respectively (Lee et al., 2005). Chlorogenic acid is a copigment known to increase the color intensity of anthocyanins (Mazza & Brouillard, 1990).

Total anthocyanin content in rabbiteye blueberries has been reported to be 136 mg cyanidin-3-glucoside equivalents/100 g of thawed blueberries (Stojanovic & Silva, 2007), 124 mg cyanidin-3-glucoside eq./100g in fresh blueberries (Prior et al., 1998), and 406 mg cyanidin-3-glucoside eq./100g fresh-frozen blueberries (Moyer et al., 2002). Total phenolics content for blueberries have been reported by many: 340 ± 14.6 mg gallic acid eq./100g fresh product (Prior

et al., 1998), 875 ± 80 mg gallic acid eq./100g fresh product (Moyer et al., 2002), 551 mg/100g fresh product or 4038 mg gallic acid eq./100g dry matter (Stojanovic & Silva, 2007), and 4180 mg gallic acid eq./100g dry matter (Velioglu et al., 1998).

1.4 Health Benefits

Blueberries, high in antioxidants, may play a role in preventing numerous diseases (Afaq et al., 2007; Andres et al., 2005; Kalea et al., 2006; Kraft et al., 2005; Pang et al., 2008; Prior et al., 2004; Sadik et al., 2008; Seeram et al., 2006; Sweeney et al., 2002). Consumption of blueberries and their products have been associated with a number of positive health benefits. Anthocyanins have been proposed to impart beneficial health effects by the reduction of age-related oxidative stress, antioxidant activity, and anti-inflammatory activity (Beattie et al., 2005; Juranic & Zeljko, 2005; Marniemi et al., 2000; Viljanen et al., 2004). Anthocyanins consist of six anthocyanidins (*i.e.*, the aglycones) linked to sugars (Parada & Aguilera, 2007). Their metabolism is not yet well understood (Wu et al., 2002). Wu et al. (2002) performed a study on the absorption and metabolism of blueberry anthocyanins/anthocyanidins and reported that the pigments with sugars attached had lower excretion than those without. Manthey (2000) reported that flavonoids reduced inflammation by decreasing prostaglandin production through inhibition of cyclooxygenase, lipoxygenase, and phospholipase.

Blueberry anthocyanins and proanthocyanidins have shown protective properties against hyperoxia in rats (Cao et al., 1999) and antiadhesion of oral bacteria (Foo et al., 2000; Weiss et al., 2002). Sprague-Dawley rats fed blueberries (8 % w powder/w food) for 13 weeks exhibited higher amounts of glycosaminoglycans (GAGs) (13 %) in the aorta than control rats (Kalea et al., 2006). GAGs play vital roles in lipoprotein metabolism, blood coagulation, cellular

proliferation, migration and adhesion, and extracellular matrix organization (Karamanos, 1998; Theocharis et al., 1999).

1.5 Production

Consumption of blueberries in the United States has more than doubled since 2001 due to consumers becoming more aware of the potential health benefits from blueberries. The demand for blueberries has led to an increase in production. The amount of acreage in Georgia harvesting blueberries started at 4,600 in 2001 and reached 13,000 acres by 2010 (USDA, 2010, 2011). The price of fresh blueberries continues to be nearly double to quadruple that of frozen blueberries (USDA, 2010). Georgia produced 41 million pounds of blueberries in 2008, representing 12 % of the total US cultivated blueberry production (USDA, 2010, 2011). Besides fresh sales, blueberries are processed into frozen fruit, purees, juices, and dried fruits. There is a need to incorporate blueberries into more products and also develop new avenues for utilization of blueberries without compromising their potential health benefits.

1.6 Preservation

Blueberries have a harvest time in Georgia between May and August with a refrigerated shelf life of a few weeks. Depending on variety, Connor et al. (2002) reported highbush blueberry shelf life varying from 7 weeks to less than 3 weeks. Fresh blueberries are mainly hand picked due to their fragile nature and tendency to split during machine harvesting. Splits in the skins greatly reduce their shelf life by encouraging mold growth, which consumers will certainly reject. Due to the large labor requirement and short shelf life, the final cost to consumers is quite high compared to frozen blueberries which usually have been machine harvested. Therefore, preservation by drying offers an excellent option to using blueberries unfit for fresh sales by extending shelf life and allowing for room temperature storage. In turn, drying reduces storage

and transportation costs associated with refrigeration and increased weight from water. Dried blueberries may add visual and taste appeal to cereals, confections, and baked goods (Feng et al., 1999).

1.7 Drying

Dried fruits have several advantages over their fresh counterparts: extended shelf life, reduced storage cost (no need for refrigeration or freezing), and reduced transportation cost (less weight). Typically, blueberries are either freeze-dried or osmotically dehydrated by the addition of a sugar solution and then hot air dried. Numerous drying techniques have been employed in an effort to achieve high quality dried blueberries. These methods include osmotic dehydration (Kim & Toledo, 1987; Lohachoompol et al., 2004; Lohachoompol et al., 2007; Nsonzi & Ramaswamy, 1998a, b; Stojanovic & Silva, 2007; Venkatachalapathy, 1998; Venkatachalapathy & Raghavan, 1998; Yang et al., 1987), explosion puffing (Sullivan et al., 1982), fluidized bed-drying (Kim & Toledo, 1987), microwave drying (Feng et al., 1999; Mejia-Meza et al., 2008; Venkatachalapathy, 1998; Venkatachalapathy & Raghavan, 1998; Yang & Atallah, 1985), hot air drying (Lohachoompol et al., 2004; Lohachoompol et al., 2007; MacGregor, 2005; Mejia-Meza et al., 2008; Stojanovic & Silva, 2007; Yang & Atallah, 1985), freeze-drying (Lohachoompol, 2007; Mejia-Meza et al., 2008; Yang et al., 1987; Yang & Atallah, 1985), and radiant zone drying (Chakraborty et al., 2009). The degree of thermal damage induced on a food during dehydration is directly proportional to temperature and drying time (Lin et al., 1998).

Knowledge of operating conditions is extremely important in achieving the highest quality product in the shortest amount of time. Improper drying conditions can lead to case hardening, which occurs when the drying rate is too high initially and moisture becomes trapped inside the surface of the product.

1.8 Pretreatment

Various chemical and physical pretreatments have been explored in an effort to reduce drying time or improve the quality of dried blueberries. Drying time has been reduced by mechanically abrading the surface of both blueberries and plums (Di Matteo et al., 2002; Lohachoompol, 2007). Chemical pretreatments have included dipping in 2.5 % ethyl oleate and 0.2 % sodium hydroxide to prevent the rupture of the blueberry skin (Feng et al., 1999). Blueberries pretreated by dipping in a 0.1 % sodium hydroxide solution exhibited a faster drying rate with increased moisture diffusivity and fewer ruptured berries than non-treated blueberries dried under infrared radiation heating (Shi et al., 2008). The treatments employed by Sullivan et al. (1982) did not successfully increase the drying rate for continuous explosion-puffed blueberries. Treatments included dipping blueberries into a 0.2 % sodium hydroxide solution for either 4 or 8 seconds, blanch steaming, or washing in mild detergent to remove the outer waxy layer.

1.9 Osmotic Dehydration

Osmotic dehydration (OD) of fruits usually involves soaking in a sugar solution for a period of time. The absorption of solute depends on the solute concentration, composition of the osmotic solution, temperature of solution, nature of infusing medium, geometry of sample, treatment time, agitation, and pressure during treatment, which in turn have a large impact on the final product characteristics (Lazarides & Mavroudis, 1996; Shi et al., 1995). Many studies have explored these variables in osmotic dehydration (Shi et al., 1995). Moreira and Sereno (2003) suggested that diffusion controlled the solute uptake in osmotic dehydration of apple. Loss of low molecular weight compounds occurs during osmotic dehydration including saccharides, organic acids, vitamins, mineral salts, and other phytochemicals (Stojanovic and Silva, 2007).

Stojanovic and Silva (2007) reported that osmotically dehydrated foods are more acceptable to consumers due to an increase in sugar content and removal of some fruit acids. Osmotic solutions vary between laboratories: Stojanovic and Silva (2007) used a 55 °Brix sucrose solution at 21 °C for 12 h, 3 h, and 3 h with ultrasound. Osmotic dehydration lowered the a_w from 0.97 to 0.93; air dehydration achieved a_w of 0.38-0.44. Osmotic dehydration and ultrasound treatments decreased the anthocyanin content 20-59 % compared to thawed samples.

Changrue et al. (2008) concluded that osmotic dehydration did not decrease the drying time or energy cost of drying halved strawberries but did yield improved sensorial qualities in the dried product. The osmotic pretreatment consisted of 60 % sucrose solution subjected to the halved strawberries 24 h at 20°C with sample to solution ratio of 1:9 w/w. The MC of the strawberries was initially 91 % and 59 % post osmotic dehydration. Other studies have shown that osmotic dehydration improved sensory qualities of dried foods (Changrue et al., 2008; Grabowski et al., 2002; Torreggiani, 1993; Torringa et al., 2001).

The waxy cuticle layer on the outside of the blueberry determines the water permeability regardless of membrane thickness (Schonherr, 1976). Therefore, the variations in waxy layer thickness between blueberry varieties will largely impact the effectiveness of osmotic dehydration. Also, Nsonzi and Ramaswamy (1998a) reported that the rate of solids gain (sucrose) was less than the moisture loss during osmotic dehydration. Increased sucrose concentration and solution temperature led to an increase in solids uptake and moisture loss (Nsonzi and Ramaswamy, 1998a). Grabowski et al. (2002) reported sugar-infused cranberries drying slower than non-infused cranberries.

Pulsed vacuum osmotic dehydration (PVOD) appears to be first defined by Shi et al. (1995) as a variation in pressure during osmotic dehydration. PVOD employs osmotic

dehydration under vacuum followed by releasing the vacuum to atmospheric pressure for a period of time. The release of vacuum causes an exchange between the internal gas within foods and the external solution, which increases the mass transfer rate (Fito, 1994; Moreno et al., 2004; Tapia et al., 1999). Shi et al. (1995) reported that the use of vacuum during osmotic dehydration increased the water loss but did not affect the solute uptake. Implementing pulsed vacuum during osmotic dehydration of apples resulted in the greatest solute uptake compared to using normal pressure, agitation, or ultrasound during OD (Deng & Zhao, 2008; Shi et al., 1995).

1.10 Hot Air Drying

Traditional hot air drying produces shrunken and tough dried products with noticeable browning, little rehydration ability, and low nutritive value (Krokida et al., 2000). Multiple studies have compared the quality, drying kinetics, and energy consumption of producing dried products by hot air drying to other drying technologies in an effort to improve quality and or increase efficiency. Temperature has a large effect on the drying of products. The drying rate of d'Agen plums at 100 °C was double the rate at 70 °C (Sabarez et al., 1997), but drying at temperatures greater than 80 °C induced Maillard and caramelization reactions at lower MC (Wilford et al., 1997). Decreasing temperature from 95 °C to 82 °C in a continuous explosion puffing system (CEPS) prevented blueberries (*V. ashei* 'Tifblue') from rupturing and reduced pigment bleeding, leading to improved drying (Sullivan et al., 1982). Drying time to achieve ~20 % moisture at 82 °C was 5 h.

One method of hot air drying is fluidized bed drying which directs hot air onto the drying belt at a controlled velocity causing the product to assume a fluidized state. Grabowski et al. (2002) noted non-homogeneous fluidized bed drying of blueberries as being due to the stickiness of sugar-infused blueberries at the beginning of drying. Strong fluidization was required for

fluidized bed drying of blueberries (Kim & Toledo, 1987; Taherian et al., 2002). Kim and Toledo (1987) reported rapid drying of blueberries from 85.3 to 41.2 % moisture at high temperatures (8 min at 170 °C for thawed berries; 4 min at 150 °C for OD berries) in a fluidized bed dryer. Drying was finished to achieve 0.5 a_w in either a fluidized bed dryer at 60 °C and 15 m/s (total drying time 1.10 h) or a tunnel dryer at 60 °C and 4 m/s (total drying time 2.13 h). Their dried blueberries exhibited less shrivel, better rehydration, and texture similar to raisins compared to hot air tunnel dried and commercially explosion puffed samples. Blueberries without osmotic dehydration pretreatment were not suitable for consumption due to case hardening.

Grabowski et al. (2007) dried blueberries to a final moisture of 15-18 % (corresponding a_w of 0.45-0.55) in a vibrated fluidized bed dryer at 85 or 90 °C and 1.4 m/s air flow. Mechanical vibrations of 30 Hz served to separate clumps of blueberries to increase the interfacial drying surface area and ultimately drying rate (Grabowski et al., 2007). Vibrated fluidized bed drying and pulsed fluidized bed drying had the highest energy efficiency for drying cranberries when compared to freeze-drying, vacuum-drying, and cabinet tunnel drying (Grabowski et al., 2002).

Mejia-Meza at al. (2008) hot air dried highbush blueberries in a custom made hot air convective dryer at 76.6 °C for 4.5 h to 5 % moisture. Lohamchoompol et al. (2004) also hot air dried highbush blueberries in a cabinet dryer using a temperature profile starting with 90 °C for 90 min followed by 120 min at 70 °C and finishing with 120 min at 50 °C. The final MC was 36.9 % for untreated blueberries and 33.6 % for sucrose-infused blueberries. Stojanovic and Silva (2007) hot air dried rabbiteye blueberries at 70 °C for 10 h with an initial MC of 86.3 % and final MC ranging from 9.4 to 13.6 % (water activity ~0.4), depending upon pretreatment. Yang and Atallah (1985) dried lowbush blueberries to 20 % moisture in a forced air convection

dryer at 70 °C for ~180 min. Compared to freeze-drying, vacuum-oven drying, and microwave-convection drying, hot air drying resulted in the greatest shrivel.

Air temperature and velocity, blueberry size, and packed bed depth impact on blueberry drying in an experimental dryer were studied by MacGregor (2005) to develop a large-scale dryer. Small berries appeared to dry more slowly but air velocity was also less (0.18 and 0.25 m/s) compared to large berries (0.30 and 0.40 m/s). Also the bed depth (50 mm) for large berries (8-16 mm) was less than that (0.75 mm) for small berries (4-5 mm). Commercial drying was split into a two-stage process starting with 82 °C followed by reducing to 71 °C with shorter drying times for small blueberries (4 h) than large blueberries (5.3 h).

1.11 Vacuum Drying

Vacuum drying has received increased attention in recent years as efforts are being made to explore alternatives to traditional hot air drying, which decrease drying time and improve quality of dried products. According to Chen and Lamb (2001) during vacuum drying, the pressure first decreases on the product surface where water quickly evaporates. The pressure inside the product continues to decrease as drying continues and the boiling front moves from the surface into the interior of the product. Water boils when the pressure becomes equal or less than the saturation pressure at the temperature of the product. Thus, drying under vacuum lowers the boiling point of water. The mass transfer during drying is increased by vacuum due to the increased pressure gradient between the outside and inside of the product while allowing moisture to escape at lower temperatures than atmospheric drying (Pere & Rodier, 2002). Vacuum has been proposed to protect products from oxidation due to the constant removal of vapor during drying (Amellal & Benamara, 2008). Amellal and Benamara (2008) noted the lack of excessive Maillard and caramelization reactions in vacuum dried date pulp to <5 % MC at 60

to 100 °C. This finding is likely due to the reduced availability of free oxygen under vacuum conditions.

Freezing drying, vacuum contact drying, and vacuum contact plus microwave drying are all drying methods which have been explored by various researchers on a variety of different products including milk (Song et al., 2002), nettle leaves (Alibas, 2007), and cranberries (Beaudry et al., 2004). Vacuum oven drying has been explored for many products, including date pulp (Amellal and Benamara, 2008), pumpkin (Arevalo-Pinedo & Murr, 2006, 2007), carrot (Arevalo-Pinedo & Murr, 2007; Devahastin et al., 2004; Kompany et al., 1993; Krokida et al., 1999; Krokida & Maroulis, 1997, 2000, 2001; Lin et al., 1998), cranberries (Beaudry et al., 2004), ginger (Hawlader et al., 2006), mango pulp (Jaya & Das, 2003), coconut presscake (Jena & Das, 2007), pharmaceutical products (Kardum et al., 2001), gelatin-microcrystalline cellulose model (King & Zall, 1992), apple (Krokida et al., 1999; Krokida et al., 2000; Krokida & Maroulis, 1997, 2000, 2001), banana (Krokida et al., 1999; Krokida & Maroulis, 1997, 2000, 2001), potato (Krokida et al., 1999; Krokida & Maroulis, 1997, 2000; Krokida et al., 2001), Asian white radish (Lee & Kim, 2009), and celery (Madamba & Liboon, 2001). Changrue et al. (2008) coupled vacuum oven drying in series with microwave drying for strawberries but the addition of microwave drying did not significantly decrease the drying time. Other studies combined vacuum drying and microwave drying into one technology: honey (Cui et al., 2008), carrots (Cui et al., 2005), fruit gels (Drouzas et al., 1999), mushrooms (Giri & Suresh, 2007a, b), apple (Kiranoudis et al., 1997), kiwi (Kiranoudis et al., 1997), pear (Kiranoudis et al., 1997), sodium carbonate-isopropanol (Kohout & Stepanek, 2007), spinach and kale (Lefsrud et al., 2008). Vacuum freeze-drying has been thoroughly studied and is often included in drying technology comparison studies, including apples slices (Hammami et al., 1999), ginger

(Hawlader et al., 2006), Saskatoon berries (Kwok et al., 2004), carrot (Lin et al., 1998), and blueberries (Lohachoompol, 2007; Mejia-Meza et al., 2008; Yang & Atallah, 1985).

Arevalo-Pinedo and Murr (2007) dehydrated pumpkin and carrot samples under 5 kPa and 15 kPa of vacuum at 50, 60, and 70 °C. Pre-frozen and blanched pumpkin samples exhibited faster drying rates and shorter drying times during vacuum drying compared to untreated samples, with pre-frozen samples having the shortest drying time (Arevalo-Pinedo & Murr, 2006). Pre-frozen samples had higher diffusivity values compared to blanched and untreated. The faster drying in the frozen samples was attributed to cell disruption due to freezing (Arevalo-Pinedo & Murr, 2007; Eshtiaghi et al., 1994; Mazza, 1983).

The basic premise of freeze-drying involves pre-freezing a product such that all free water is frozen. Then the application of vacuum allows the product to reach its triple point which is temperature and pressure specific when the frozen water sublimates and leaves the product as a vapor. An increase in plate temperature signals the secondary drying stage to remove bound water. Chemical and thermal degradation nearly do not occur in freeze-dried products due to the low temperatures inherent in the freeze-drying process (Song et al., 2002). Yang and Atallah (1985) found freeze-drying and vacuum oven drying produced dried lowbush blueberries with greater rehydration ability and improved color than forced hot air or microwave-convective drying. Blueberries were freeze-dried 660 min or to 16-25 % moisture. Lefsrud et al. (2008) (2008) reported no significant difference between -25 and 25 °C freeze-drying spinach and its lutein, β-carotene, and chlorophyll content. 25 °C was determined to be the maximum temperature for freeze-drying or convective drying spinach and kale to maintain quality and nutritive stability (Lefsrud et al., 2008). Shishehgarha et al. (2002) freeze-dried strawberries up to 70 °C without significant affect on quality although higher temperatures increased risk of

structural collapse. Freeze-drying is a well known method for achieving the highest quality dried product (Drouzas & Schubert, 1996; Hosseinian & Beta, 2007; Larrauri et al., 1997; Methakhup et al., 2005; Shishehgarha et al., 2002) with minimal shrinkage, softer texture, better rehydration capacity, better color retention, and more porous structure compared to hot air drying between 55 - 70 °C (Beaudry et al., 2004; Deng and Zhao, 2008; Krokida et al., 2000).

Combining vacuum drying with microwave drying has received increased interest for its use in foods (Changrue et al., 2008; Stojanovic & Silva, 2007; Sunjka et al., 2008) and pharmaceuticals (McMinn et al., 2007). The application of microwaves, which excite water molecules through the entire sample, and the addition of vacuum creates a large pressure difference between the inside and surface of the material, preventing structural collapse and encouraging moisture migration out of the sample. Changrue et al. (2008) vacuum-microwave dried (VMD) strawberries to 7 % MC (corresponding a_w of 0.52-0.57) at 8 kPa absolute pressure. Lin et al. (1998) compared quality characteristics of dried carrots after vacuum-microwave, hot air, and freeze-drying. Vacuum-microwave drying exhibited better color, density, rehydration, texture and nutritive content than hot air drying. Freeze-drying excelled with better rehydration, nutritive content, and appearance in dried carrots compared to hot air and vacuum-microwave dried product.

Sunjka et al. (2008) dried cranberries in a microwave-vacuum oven following osmotic dehydration. They varied continuous and pulsed microwaves using three power levels (1, 1.25, 1.5 W/g of initial sample mass) and vacuum settings (3.4, 18.6, 33.8 kPa abs. pressure). Drying time, color, toughness, and rehydration ratio of the samples were measured. Their findings that pulsed microwave power and greater vacuum (3.4 kPa) achieved the highest quality dried cranberries determined by color, texture, moistness, and rehydration properties agreed with those

published by Yongsawatdigul and Gunasekaran (1996). Sunjka et al. (2008) suggested using a rotating tray or moving belt to achieve better thermal distribution across the drying sample.

The vacuum-belt dryer is a promising technology, operating as a continuous or semi-continuous drying system with less heat damage to products than conventional hot air drying. Little research has been published on a continuous vacuum-belt drying system. Existing studies were published over 15 years ago (Ferrari & Hinz, 1991; Kumazawa et al., 1984; Kumazawa et al., 1990; Kumazawa et al., 1991; Osinskij, 1994). Other studies implementing the vacuum-belt drying technology have included apple, pear, apricot, and peach juices (Maltini et al., 1992), herbal extract (Liu et al., 2011; Liu et al., 2009), muscadine pomace (Vashisth et al., 2011), and bananas (Wang et al., 2007a). When the present work began in 2008, only the study by Maltini et al. (1992) had been published on the vacuum belt drying of fruit juice into powders. The vacuum belt dryer described by Liu et al. (2009) had two conduction heating plates but did not have a radiation plate or other drying mechanism over the belt as described by Vashisth et al. (2011). Liu et al. (2009) Vacuum belt dried extract from *Panax notoginseng* root at various conduction plate temperatures (90, 100, and 110 °C). The data indicated that belt speed (4-10 cm/min), conduction plate temperature (90-110 °C), and throughput (15-25 mL/min) affected the drying time. The Logarithmic drying model best fit the moisture data (r^2=0.99). Vacuum belt dried *P. notoginseng* root extract took significantly less time (30 min) than freeze-drying (24 h) or vacuum oven drying (28 h) (Liu et al., 2011). The saponin content of vacuum belt dried ginseng extract was comparable to extract dried by vacuum drying, freeze-drying, and spray drying, but the vacuum belt dried ginseng extract exhibited notably higher hydrogen peroxide scavenging rate. Another study by Vashisth et al. (2011) reported similar total phenolics content and antioxidant activity in vacuum belt dried muscadine pomace powder to freeze-dried pomace.

Like the aforementioned studies, vacuum belt drying significantly reduced the drying time (14 h to 60 min).

A study presented at the Chinese Society of Agricultural Engineering highlighted the benefits of a continuous vacuum belt dryer: good protection of nutritional quality, large flavor retention, little color change, and one-fifth operation time compared to freeze-drying (Wang et al., 2007b). The same laboratory studied the volatile retention in drying banana puree, concluding that freeze-drying retained the most characteristic banana aromas followed by vacuum belt drying and then hot air drying (Wang et al., 2007a). Vacuum belt drying was performed with plate temperatures varying between 210 and 50 °C at 1.15 kPa. The loss of volatiles was attributed to higher heating temperatures during vacuum belt drying and hot air drying.

Advantages of vacuum drying include the lowering of the boiling point of water under vacuum, improved internal mass migration because of pressure gradients caused by vacuum, and decreasing resistance of mass transfer from the boundary layer due to vacuum (Defo et al., 2000). For example, the boiling point of water is reduced to 39 °C at 7 kPa of absolute pressure, which is the pressure achieved in most vacuum drying applications (Barbosa-Canovas & Vega-Mercado, 1996). Vacuum expands air and water vapor present in the food, creating a frothy or puffed structure (Jaya & Das, 2003). Sufficient drying creates a product which maintains its structure upon pressure release. Structural collapse or shrinkage can indicate inadequate drying conditions.

1.12 Moisture Content

Moisture content is the measure of the amount of water present in a product. The basic premise of drying involves the removal of moisture from a product to a desired level, usually less

than 20 % for fruits, to extend shelf life and provide alternative uses beyond that of fresh foods. Powders typically require less than 6 % MC to prevent sticking (Amellal and Benamara, 2008). The final moisture is a critical result considered in all drying processes. Moisture loss is controlled by mass transfer kinetics of the drying process and food.

Moisture content is most often reported as a percentage on a dry basis (db) or wet basis (wb) of water to the dried solids or total solids, respectively.

1.13 Water Activity

Water activity, a_w, is a critical factor in predicting the microbial, physical and chemical stability of food. Water activity is defined as the ratio of the vapor pressure of water in a material to the vapor pressure of pure water at the same temperature (Fontana, 2006), ranging from 1.0 for pure water to 0.0 for a bone dry product. Different microorganisms grow at varying a_w values; likewise, chemical reactions such as browning and lipid oxidation vary with a_w. All pathogenic bacteria require a_w greater than 0.85. Yeast and mold growth are inhibited at a_w below 0.61 (Fontana, 2006).

Moisture sorption isotherms relate water content to water activity and differ for each type of food and method of drying. The desorption isotherm is the most relevant for drying. The monolayer value of water can be determined from the Guggenheim-Anderson-DeBoer (GAB) model, which can be used to indicate the water content corresponding to product stability. (Klewicki et al., 2009) measured moisture isotherms of several fruits (apple, blackcurrents, and sour cherries) and recommended drying to a a_w between 0.45 to 0.63 with freeze-dried fruits being more stable at lower a_w values than infused and hot air dried (60 °C) fruits.

1.14 Quality of Dried Products

Processing induces various changes to physical, biological, and chemical characteristics of foods. Changes in characteristics after drying can include color loss, shrinkage, aroma loss, and nutritional degradation. Drying time and temperature are the primary factors responsible for quality loss in dried fruits and vegetables (Feng et al., 1999; Strumillo et al., 1996; Yang & Atallah, 1985).

1.15 Colorimetry

The color of foods greatly influences quality evaluation (Saftner et al., 2008). The red flavylium and blue quinodal anthocyanins contribute the majority of the characteristic color of blueberries (Mazza & Brouillard, 1987).

L* values indicate the lightness of a sample with 100 indicating white to 0 indicating black. An increase in the L* value correlates to a lighter sample. Feng et al. (1999) reported thawed blueberries having an L* value of 31 with an increased L* value to 38 for dried blueberries. Venkatachalapathy (1998) reported the L* value of fresh blueberries as 27 with a reduction in the L* value, 13 – 20, after freeze-drying or microwave drying. Yang and Atallah (1985) reported all drying methods (freeze-drying, hot air, vacuum oven, and microwave-hot-air drying) increased the L* values of blueberries compared to frozen blueberries. An increase in lightness of dried strawberries and blueberries has been attributed to heat degradation of pigments (Contreras et al., 2008; Yang & Atallah, 1985).

Hue is expressed as the angle formed between the –a* axis and b* axis (Clydesdale, 1984), calculated as the arctan (b*/a*). McGuire (1992) related color to different hue angles: 0 ° as red-purple, 90 ° as yellow, 180 ° as blue-green, and 270 ° as blue. Phytochemical content and concentration are largely responsible for the varying colors in fruits and vegetables which can be

related to the hue angle (Gonçalves et al., 2007). Feng et al. (1999) reported a* and b* values, for which the hue was calculated as 335 ° for thawed 'Elliot' blueberries, 310 ° for freeze-dried blueberries, 328 ° for osmotically dehydrated-microwave spouted bed dried blueberries, and 353 ° for tray dried blueberries.

Chroma indicates the intensity of color in a sample (Abers & Wrolstad, 1979; Voss, 1992). Calculated chroma values, $(a^2 + b^2)^{½}$, from reported a* and b* values by Feng et al. (1999) ranged from 0.25 for osmotically dehydrated-microwave spouted bed dried blueberries to 3.15 for non-treated microwave spouted bed dried blueberries. Thawed blueberries had a chroma of 1.78 (Feng et al., 1999).

Krokida et al. (1998) investigated color changes in banana, carrot, potato, and apple during conventional hot air and vacuum drying and reported a first-order kinetic model relating temperature and relative humidity to color change during drying.

Stojanovic and Silva (2007) reported no significant change in L, hue, and chroma values as a result of osmotic concentration of rabbiteye blueberries. On the contrary, Contreras et al. (2008) reported color loss in osmotically dehydrated strawberries most noted in the decrease in the chroma from 22 to 12. Air drying at 40 °C further reduced chroma to 8.9 in PVOD strawberries and 14.8 in non-treated strawberries. Color measurements can indicate loss of pigments such as anthocyanins, browning due to Maillard reactions or enzymatic degradation, and influence sensory evaluation. Color has been shown to influence the sweetness and flavor intensity of a food (Christensen, 1983; Clydesdale, 1991, 1993).

1.16 Sensory

Sensory is a vital component of product development. Regardless of the energy efficiency and novelty of a food process, food products must be not only acceptable but desirable

for consumption by consumers. Without consumers buying a product, there is no market or reason to produce a particular product. Therefore the attributes, acceptability, and willingness to buy are all important considerations in the development of a food or food process. Several classes of sensory tests may be employed to evaluate foods: descriptive, differential, and affective testing. While several reports on the sensory attributes of blueberries have been published (Makus & Morris, 1993), few studies have reported sensory attributes of dried fruits, especially blueberries.

Venkatachalapathy (1998) performed sensory evaluation of blueberries osmotically dehydrated followed by freeze-drying, microwave drying, or convection drying. The panel consisted of 10 judges. Judges were asked to rate the samples on appearance, aroma, taste and color using a 9 point Hedonic scale from like extremely to dislike extremely. The acceptability of the dried blueberries was highest for freeze-dried blueberries followed by microwave-dried and then convection-dried blueberries but only a significant difference in acceptability existed between the freeze-dried and convection dried blueberries.

Saftner et al. (2008) compared the sensory characteristics of 10 highbush and 2 rabbiteye blueberry cultivars to instrumental measurements. They reported that flavor followed by juiciness intensity, skin toughness, sweetness and appearance acceptability best indicated overall eating quality of blueberries. Significant differences in sensory attributes existed between blueberry cultivars (Makus & Morris, 1993; Saftner et al., 2008).

1.17 Phytochemical Stability

Due to the potential health benefits of blueberries, it is important to know the effects of drying on their nutritive content, especially the phytochemicals. A lot of research has explored the antioxidant extraction, identification, and activity for many cultivars of fresh and frozen

blueberries (Castrejón et al., 2008; Ehlenfeldt & Prior, 2001; Hosseinian & Beta, 2007; Hosseinian et al., 2007; Kalt et al., 2001; Latti et al., 2008; Lohachoompol et al., 2008; Nicoue et al., 2007; Prior et al., 1998; Prior et al., 2003; Rimando et al., 2004; Schmidt et al., 2004; Scibisz & Mitek, 2007; Sellappan et al., 2002; Smith et al., 2000; Wang & Lin, 2000; Wu et al., 2004). Only a few studies have measured the effects of dehydration on the antioxidant activity of blueberries (Chakraborty et al., 2009; Kalt et al., 2000; Lohachoompol, 2007; Lohachoompol et al., 2004; Mejia-Meza et al., 2008; Stojanovic & Silva, 2007; Vaghri et al., 2000).

One study published by Kalt et al. (2000) compared the antioxidant activity of fresh, frozen, pureed, baked, canned, juiced, and commercially dried lowbush blueberry samples. The dried blueberry samples were subcategorized into intermediate moisture, low moisture, cereal fruit, and sugar-infused fruit. The intermediate moisture dried blueberries had the highest antioxidant activity followed by low moisture and sugar infused blueberries.

Schmidt et al. (2005) measured the total phenolics content, antioxidant capacity, and antiproliferation activity on hepa-1c1c7 murine liver cancer cells for many blueberries products: fresh, IQF, freeze-dried, cooked, canned, spray-dried, jam, juice, hot air dried, and pie filling. Products processed with heat (cooked, canned, spray-dried, jam, juice, sweetened and hot air dried, and pie filling) showed little, if any, antiproliferative activity compared to fresh, individually quick frozen (IQF), and freeze-dried samples, and, interestingly, the antiproliferative activity did not correlate with the total phenolics content or antioxidant activity of the samples.

Brownmiller et al. (2008) studied processing and storage effects on the monomeric anthocyanins content and antioxidant capacity (H-ORAC$_{FL}$) of blueberries canned in syrup, canned in water, pureed, and juiced. These authors declared a need for reducing anthocyanin loss in processed blueberries. Kwok et al. (2004) reported an 85 % decrease in anthocyanin content in

air dried Saskatoon berries at 75 °C. They compared the phenolic and anthocyanin content of Saskatoon berries after drying. The total phenolics and anthocyanin content of dried Saskatoon berries were highest after freeze-drying followed by vacuum microwave drying and lowest in air drying and vacuum microwave combined with air-drying (Kwok et al., 2004).

The total monomeric anthocyanin content (TMA) is most often measured by the pH differential method developed by Giusti and Wrolstad (2001) measuring the difference between sample absorbance values at pH 1.0 and 4.5 and 520 and 700 nm. Malvidin-3-*O*-galactoside was the predominant anthocyanin in rabbiteye 'Tifblue' blueberries (Prior et al., 2001). Despite malvidin being the main blueberry anthocyanidin, blueberry values are typically reported in milligrams of cyanidin-3-*O*-glucoside (C3G) equivalents per gram of extract, dry matter, or fresh weight blueberry. This is likely due to studies on a variety of fruits containing anthocyanins, most of which contain C3G, but may not have all anthocyanins. For example, unlike blueberries cranberries do not contain malvidin, but both contain C3G.

Kalt (2005) published a review on production and processing factors of fruits and vegetables regarding vitamin C, carotenoid, and phenolic content. They found that carotenoids were less affected by processing than vitamin C and phenolic compounds due to their hydrophilic nature. The total phenolics content is based on the absorbance at 750 nm of phosphomolybdic-phosphotungstic acid complex formed by the reaction between the Folin-Ciocalteu reagent and phenolic moieties in a sample under alkali conditions. The TPC of blueberries is usually related to gallic acid equivalents (GAE). Antioxidant capacity has been measured by several methods including Trolox equivalent antioxidant capacity (TEAC), oxygen radical absorbance capacity (ORAC), 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging activity, and ferric reducing antioxidant potential (FRAP). ORAC involves hydrogen atom

transfer reactions while TEAC, FRAP, and DPPH involve electron transfer reactions (Huang et al., 2005). TEAC and ORAC methods are based on inhibition of free radical generation over time. FRAP measures the antioxidant reducing ability but not antioxidant radical quenching activity. FRAP is simple and relatively inexpensive whereas ORAC is a very specific and highly involved method.

Anthocyanins are very unstable due to their reactive nature. Specific stability depends on their structure, concentration, pH, temperature, light, metallic ions, enzymes, oxygen, ascorbic acid, sugars, proteins, and sulfur dioxide (Ersus & Yurdagel, 2007; Rodríguez-Saona et al., 1999; Skrede et al., 2000). Delphinidin and cyanidin glycosides have higher H-$ORAC_{FL}$ values than malvidin, pelargonidin, and peonidin glycosides (Wang et al., 1997). Delphinidin glycosides are likely most reactive due to the presence of three hydroxy groups in the B ring. Cyanidin glycosides have two hydroxy groups in the B ring. The least reactive anthocyanins, malvidin and peonidin glycosides, have one hydroxy group in the B ring with adjacent methoxy groups.

Only a few studies have been published on the effects of drying on the phytochemical compounds in blueberries (Chakraborty et al., 2009; Lohachoompol et al., 2004; Stojanovic and Silva, 2007; Mejia-Meza et al., 2008; Vaghri et al., 2000).

Lohachoompol et al. (2004) cabinet-dried highbush blueberries (*Vaccinium corymbosum* L.) varying pretreatment and drying temperature and time (90 °C-90 min, 70 °C-120 min, 50 °C-120 min). The authors reported lower anthocyanin content for osmotically pretreated blueberries (60 % aq. sucrose, 1 % NaCl for 4 h) than non-treated blueberries. Interestingly, no significant difference in antioxidant activity of the anthocyanin extracts, measured by DPPH, between dried and fresh berries was found. The authors proposed that the compounds resulting from the breakdown of the anthocyanins during drying may have antioxidant activity. Other products

produced during drying such as Maillard reaction products including melanoids may contribute to antioxidant capacity in dried foods (Bedinghaus & Ockerman, 1995; Kitts & Hu, 2005).

Another study reported by Mejia-Meza et al. (2008) compared the antioxidant activity of highbush blueberries after drying with freeze-drying having the highest retention, followed by hot air-microwave vacuum drying, microwave vacuum drying, and hot air drying. Yue and Xu (2008) studied the effects of dry heat via sand bath on bilberry anthocyanins, anthocyanidins, and antioxidant activity. They found that heating at 125 °C for 30 min caused significant degradation in free radical scavenging capacity compared to heating at 80 or 100 °C for the same amount of time.

Stojanovic and Silva (2007) concluded that long drying time, presence of oxygen, high temperature, and high sugar concentration all contributed to the decrease in anthocyanin content. Osmotic dehydration and ultrasound treatments decreased the anthocyanin content 20 - 60 % compared to thawed blueberries, and hot air dehydration at 70 °C for 10 h further decreased anthocyanin content 69 % (Stojanovic and Silva, 2007). They suggested decreasing the time of osmotic dehydration, processing in reduced oxygen environment or under vacuum conditions, and recycling of the sucrose solution would improve the drying process both nutritionally and economically.

Omitting the pretreatment of osmotic dehydration via sugar solution with $CaCl_2$ resulted in less loss of soluble phenolic compounds, anthocyanins, and antioxidant capacity (Bohm et al., 2006). Phenolic content tends to be more resistant to losses during drying compared to anthocyanin content (Kalt et al., 2000; Stojanovic and Silva, 2007). The difference between free and total phenolics content of dried strawberries being phenolic compounds bound to the matrix

(Bohm et al., 2006). Minimizing temperature spikes during drying increased the retention of ascorbic acid and total phenolics compounds (Bohm et al., 2006).

Radiant zone drying is a new method of continuous drying. Chakraborty et al. (2009) produced highbush blueberry powders by depositing blueberry extract, juice, and puree separately onto a continuous belt system which passed over 5 consecutive infrared red heat plates. The temperature profile began with 65 °C and increased gradually to ~90 °C. Powders were produced in six to ten min. Drying did not significantly affect the anthocyanin content (11.7-11.2 mg C3G eq./g dm), total phenolics content (113-97 mg GAE/g dm), or antioxidant activity (23.6-22.3 mmol TE/g dm) of the wet and dry blueberry extracts, respectively. The extract powder had the highest amount of anthocyanins and total phenolics content compared to the juice and puree powders. The authors proposed radiant zone drying to be a potential alternative to freeze-drying due its continuous design and retention of bioactive compounds. Two disadvantages to freeze-drying are the batch process and long drying times which lead to higher production costs than continuous hot air drying methods.

Vaghri et al. (2000) dried two cultivars of highbush blueberries by vacuum microwave, hot, freeze, and combined hot air with vacuum microwave drying. Anthocyanin and phenolic content was higher in vacuum microwave dried blueberries (a_w 0.450 – 0.490) than blueberries dried 12.5 h in hot air at 70 °C to a_w of 0.537 - 0.592. The authors reported higher anthocyanin content in freeze-dried blueberries (319-574 mg anthocyanins/100g dm) compared to frozen non-dried blueberries (258-530 mg anthocyanins/100g dm). Unfortunately the anthocyanin equivalent was not specified. The phenolics content of vacuum microwave dried blueberries was similar to untreated blueberries. Air drying reduced the phenolics content nearly 30 %. In general, reduced anthocyanin and phenolic content could be attributed to long drying times.

1.18 Objectives of This Work

For the two studies involving vacuum belt drying, the objectives included the following:

- Develop drying time-temperature conditions to achieve a wide range of MC and a_w values, starting with refrigerated or frozen blueberries.
- Better understand the impact of blueberry size, physical pretreatment, conduction temperature, radiation temperature, drying duration, and their interactions on the MC and a_w of vacuum belt dried blueberries.
- Determine the impact of drying conditions on the antioxidant retention of cultivated blueberries by measuring TMA, TPC, and H-ORAC$_{FL}$.

The later two studies focused on the following objectives:

- Identify processing conditions and treatments for drying blueberries in a JetZone fluidized bed dryer while maximixing quality and minimizing processing time.
- Determine the effects of dryer temperature, pre-abrasion of the blueberries, osmodehydration with sugar solutions, and blueberry size on the drying time.
- Determine the impact of drying conditions on color, sensory scores, TMA, TPC, and H-ORAC$_{FL}$ of JetZone fluidized bed dried blueberries.
- Evaluate the effects of JetZone fluidized bed drying and osmotic dehydration on the moisture properties, TMA, TPC, antioxidant capacity, color, and sensory properties of five rabbiteye blueberry cultivars.

References

Abers, J.E. & Wrolstad, R.E., (1979). Causative factors of color deterioration in strawberry preserves during processing and storage. *Journal of Food Science* 44(1), 75-78.

Afaq, F., Syed, D.N., Malik, A., Hadi, N., Sarfaraz, S., Kweon, M.H., Khan, N., Zaid, M.A. & Mukhtar, H., (2007). Delphinidin, an anthocyanidin in pigmented fruits and vegetables, protects human HaCaT keratinocytes and mouse skin against UVB-mediated oxidative stress and apoptosis. *Journal of Investigative Dermatology* 127(1), 222-232.

Alibas, I., (2007). Energy consumption and colour characteristics of nettle leaves during microwave, vacuum and convective drying. *Biosystems Engineering* 96(4), 495-502.

Allan-Wojtas, P.M., Forney, C.F., Carbyn, S.E. & Nicholas, K.U.K.G., (2001). Microstructural indicators of quality-related characteristics of blueberries--An integrated approach. *LWT - Food Science and Technology* 34(1), 23-32.

Amellal, H. & Benamara, S., (2008). Vacuum drying of common date pulp cubes. *Drying Technology* 26(3), 378-382.

Andres, A., Rodriguez-Barona, S. & Barat, J.M., (2005). Analysis of some cod-desalting process variables. *Journal of Food Engineering* 70(1), 67-72.

Arevalo-Pinedo, A. & Murr, F.E.X., (2006). Kinetics of vacuum drying of pumpkin (*Cucurbita maxima*): Modeling with shrinkage. *Journal of Food Engineering* 76(4), 562-567.

Arevalo-Pinedo, A. & Murr, F.E.X., (2007). Influence of pre-treatments on the drying kinetics during vacuum drying of carrot and pumpkin. *Journal of Food Engineering* 80(1), 152-156.

Awad, A.M., Jager, A. & Westing, L.M., (2000). Flavonoid and chlorogenic acid levels in apple fruit: Characterization of variation. *Scientia Horticulturae* 83(3-4), 249-263.

Barbosa-Canovas, G.V. & Vega-Mercado, H., (1996). *Dehydration of foods*. Chapman & Hall, New York.

Beattie, J., Crozier, A. & Duthie, G.G., (2005). Potential health benefits of berries. *Current Nutrition & Food Science* 1(1), 71-86.

Beaudry, C., Raghavan, G.S.V., Ratti, C. & Rennie, T.J., (2004). Effect of four drying methods on the quality of osmotically dehydrated cranberries. *Drying Technology* 22(3), 521-539.

Bedinghaus, A.J. & Ockerman, H.W., (1995). Antioxidative Maillard reaction products from reducing sugars and free amino acids in cooked ground pork patties. *Journal of Food Science* 60(5), 992-995.

Bohm, V., Kuhnert, S., Rohm, H. & Scholze, G., (2006). Improving the nutritional quality of microwave-vacuum dried strawberries: A preliminary study. *Food Science and Technology International* 12(1), 67-75.

Brownmiller, C., Howard, L.R. & Prior, R.L., (2008). Processing and storage effects on monomeric anthocyanins, percent polymeric color, and antioxidant capacity of processed blueberry products. *Journal of Food Science* 73(5), H72-H79.

Cao, G., Shukitt-Hale, B., Bickford, P.C., Joseph, J.A., McEwen, J. & Prior, R.L., (1999). Hyperoxia-induced changes in antioxidant capacity and the effect of dietary antioxidants. *Journal of Applied Physiology* 86(6), 1817-1822.

Castrejón, A.D.R., Eichholz, I., Rohn, S., Kroh, L.W. & Huyskens-Keil, S., (2008). Phenolic profile and antioxidant activity of highbush blueberry (*Vaccinium corymbosum* L.) during fruit maturation and ripening. *Food Chemistry* 109(3), 564-572.

Chakraborty, M., Savarese, M., Harbertson, E., Harbertson, J. & Ringer, K.L., (2009). Effect of the novel radiant zone drying method on anthocyanins and phenolics of three blueberry liquids. *Journal of Agricultural and Food Chemistry* 58(1), 324-330.

Changrue, V., Orsat, V. & Raghavan, G.S.V., (2008). Osmotically dehydrated microwave-vacuum drying of strawberries. *Journal of Food Processing and Preservation* 32(5), 798-816.

Chen, Z.J. & Lamb, F.M., (2001). Investigation of boiling front during vacuum drying of wood. *Wood and Fiber Science* 33(4), 639-647.

Christensen, C.M., (1983). Effects of color on aroma, flavor and texture judgements of foods. *Journal of Food Science* 48(3), 787-790.

Clydesdale, F.M., (1991). Color perception and food quality. *Journal of Food Quality* 14(1), 61-74.

Clydesdale, F.M., (1993). Color as a factor in food choice. *Critical Reviews in Food Science and Nutrition* 33(1), 83-101.

Connor, A.M., Luby, J.J., Hancock, J.F., Berkheimer, S. & Hanson, E.J., (2002). Changes in fruit antioxidant activity among blueberry cultivars during cold-temperature storage. *Journal of Agricultural and Food Chemistry* 50(4), 893-898.

Contreras, C., Martin-Esparza, M.E., Chiralt, A. & Martinez-Navarrete, N., (2008). Influence of microwave application on convective drying: Effects on drying kinetics, and optical and mechanical properties of apple and strawberry. *Journal of Food Engineering* 88(1), 55-64.

Cui, Z.W., Sun, L.J., Chen, W. & Sun, D.W., (2008). Preparation of dry honey by microwave-vacuum drying. *Journal of Food Engineering* 84(4), 582-590.

Cui, Z.W., Xu, S.Y., Sun, D.W. & Chen, W., (2005). Temperature changes during microwave-vacuum drying of sliced carrots. *Drying Technology* 23(5), 1057-1074.

de Pascual-Teresa, S., Santos-Buelga, C. & Rivas-Gonzalo, J.C., (2000). Quantitative analysis of flavan-3-ols in Spanish foodstuffs and beverages. *Journal of Agricultural and Food Chemistry* 48(11), 5331-5337.

Defo, M., Cloutier, A. & Fortin, Y., (2000). Modeling vacuum-contact drying of wood: The water potential approach. *Drying Technology* 18(8), 1737-1778.

Deng, Y. & Zhao, Y.Y., (2008). Effect of pulsed vacuum and ultrasound osmopretreatments on glass transition temperature, texture, microstructure and calcium penetration of dried apples (Fuji). *LWT - Food Science and Technology* 41(9), 1575-1585.

Devahastin, S., Suvarnakuta, P., Soponronnarit, S. & Mujumdar, A.S., (2004). A comparative study of low-pressure superheated steam and vacuum drying of a heat-sensitive material. *Drying Technology* 22(8), 1845-1867.

Drouzas, A.E. & Schubert, H., (1996). Microwave application in vacuum drying of fruits. *Journal of Food Engineering* 28(2), 203-209.

Drouzas, A.E., Tsami, E. & Saravacos, G.D., (1999). Microwave/vacuum drying of model fruit gels. *Journal of Food Engineering* 39(2), 117-122.

Ehlenfeldt, M.K. & Prior, R.L., (2001). Oxygen radical absorbance capacity (ORAC) and phenolic and anthocyanin concentrations in fruit and leaf tissues of highbus blueberry. *Journal of Agricultural and Food Chemistry* 49(5), 2222-2227.

Ersus, S. & Yurdagel, U., (2007). Microencapsulation of anthocyanin pigments of black carrot (*Daucuscarota* L.) by spray drier. *Journal of Food Engineering* 80(3), 805-812.

Eshtiaghi, M.N., Stute, R. & Knorr, D., (1994). High pressure and freezing pretreatment effects on drying, rehydration, texture and color of green beans, carrots and potatoes. *Journal of Food Science* 59(6), 1168-1170.

Feng, H., Tang, J.M., Mattinson, D.S. & Fellman, J.K., (1999). Microwave and spouted bed drying of frozen blueberries: The effect of drying and pretreatment methods on physical properties and retention of flavor volatiles. *Journal of Food Processing and Preservation* 23(6), 463-479.

Ferrari, F. & Hinz, W., (1991). Neuer pilot-vakuumbandtrockner fur vielseitigen einsatz New pilot vacuum belt dryer for a variety of applications. *Chemie-Technik (Heidelberg)* 20(4), 83-84.

Fito, P., (1994). Modelling of vacuum osmotic dehydration of food. *Journal of Food Engineering* 22(1-4), 313-328.

Fontana, A., (2006). Fundamentals of Water Activity. Decagon Devices, Pullman, WA.

Foo, L.Y., Lu, Y.R., Howell, A.B. & Vorsa, N., (2000). The structure of cranberry proanthocyanidins which inhibit adherence of uropathogenic P-fimbriated Escherichia coli in Vitro. *Phytochemistry* 54(2), 173-181.

Gao, L. & Mazza, G., (1994). Quantitation and distribution of simple and acylated anthocyanins and other phenolics in blueberries. *Journal of Food Science* 59(5), 1057-1059.

Giri, S.K. & Suresh, P., (2007a). Drying kinetics and rehydration characteristics of microwave-vacuum and convective hot-air dried mushrooms. *Journal of Food Engineering* 78, 512-521.

Giri, S.K. & Suresh, P., (2007b). Optimization of microwave-vacuum drying of button mushrooms using response-surface methodology. *Drying Technology* 25(4/6), 901-911.

Giusti, M.M. & Wrolstad, R.E., (2001). Characterization and measurement of anthocyanins by spectroscopy. Unit F1.2, in: Wrolstad, R.E. (Ed.), *Current Protocols in Food Analytical Chemistry*. John Wiley & Sons, Inc., New York, pp. F1.2.1-F1.2.13.

Golding, J.B., McGlasson, W.B., Wyllie, S.G. & Leach, D.N., (2001). Fate of apple peel phenolics during cool storage. *Journal of Agricultural and Food Chemistry* 49(5), 2283-2289.

Gonçalves, B., Silva, A.P., Moutinho-Pereira, J., Bacelar, E., Rosa, E. & Meyer, A.S., (2007). Effect of ripeness and postharvest storage on the evolution of colour and anthocyanins in cherries (*Prunus avium L.*). *Food Chemistry* 103(3), 976-984.

Grabowski, S., Marcotte, M., Poirier, M. & Kudra, T., (2002). Drying characteristics of osmotically pretreated cranberries - Energy and quality aspects. *Drying Technology* 20(10), 1989-2004.

Grabowski, S., Marcotte, M., Quan, D., Taherian, A.R., Zareifard, M.R., Poirier, M. & Kudra, T., (2007). Kinetics and quality aspects of Canadian blueberries and cranberries dried by osmo-connective method. *Drying Technology* 25(2), 367-374.

Hammami, C., Rene, F. & Marin, M., (1999). Process-quality optimization of the vacuum freeze-drying of apple slices by the response surface method. *International Journal of Food Science and Technology* 34(2), 145-160.

Hawlader, M.N.A., Perera, C. & Tian, M., (2006). Comparison of the retention of 6-gingerol in drying of ginger under modified atmosphere heat pump drying and other drying methods. *Drying Technology* 24(1), 51-56.

Hosseinian, F.S. & Beta, T., (2007). Saskatoon and wild blueberries have higher anthocyanin contents than other Manitoba berries. *Journal of Agricultural and Food Chemistry* 55(26), 10832-10838.

Hosseinian, F.S., Li, W., Hydamaka, A.W., Tsopmo, A., Lowry, L., Friel, J. & Beta, T., (2007). Proanthocyanidin profile and ORAC values of Manitoba berries, chokecherries, and seabuckthorn. *Journal of Agricultural and Food Chemistry* 55(17), 6970-6976.

Howard, L., Clark, J.R. & Brownmiller, C., (2003). Antioxidant capacity and phenolic content in blueberries as affected by genotype and growing season. *Journal of the Science of Food and Agriculture* 83(12), 1238-1247.

Huang, D.J., Ou, B.X. & Prior, R.L., (2005). The chemistry behind antioxidant capacity assays. *Journal of Agricultural and Food Chemistry* 53(6), 1841-1856.

Jaya, S. & Das, H., (2003). A vacuum drying model for mango pulp. *Drying Technology* 21(7), 1215-1234.

Jena, S. & Das, H., (2007). Modelling for vacuum drying characteristics of coconut presscake. *Journal of Food Engineering* 79(1), 92-99.

Juranic, Z. & Zeljko, Z., (2005). Biological activities of berries: From antioxidant capacity to anti-cancer effects. *Biofactors* 23(4), 207-211.

Kalea, A.Z., Lamari, F.N., Theocharis, A.D., Cordopatis, P., Schuschke, D.A., Karamanos, N.K. & Klimis-Zacas, D.J., (2006). Wild blueberry (*Vaccinium angustifolium*) consumption affects the composition and structure of glycosaminoglycans in Sprague-Dawley rat aorta. *Journal of Nutritional Biochemistry* 17(2), 109-116.

Kalt, W., (2005). Effects of production and processing factors on major fruit and vegetable antioxidants. *Journal of Food Science* 70(1), R11-R19.

Kalt, W., Lawand, C., Ryan, D.A.J., McDonald, J.E., Donner, H. & Forney, C.F., (2003). Oxygen radical absorbing capacity, anthocyanin and phenolic content of highbush blueberries (*Vaccinium corymbosum* L.) during ripening and storage. *Journal of the American Society for Horticultural Science* 128(6), 917-923.

Kalt, W. & McDonald, J.E., (1996). Chemical composition of lowbush blueberry cultivars. *Journal of the American Society for Horticultural Science* 121(1), 142-146.

Kalt, W., McDonald, J.E. & Donner, H., (2000). Anthocyanins, phenolics, and antioxidant capacity of processed lowbush blueberry products. *Journal of Food Science* 65(3), 390-393.

Kalt, W., Ryan, D.A.J., Duy, J.C., Prior, R.L., Ehlenfeldt, M.K. & Vander Kloet, S.P., (2001). Interspecific variation in anthocyanins, phenolics, and antioxidant capacity among genotypes of highbush and lowbush blueberries (*Vaccinium* section *cyanococcus* spp.). *Journal of Agricultural and Food Chemistry* 49(10), 4761-4767.

Karamanos, N.K., (1998). Glycosylation of proteins: Specificity, biological role, and analysis of glycan moieties. *Journal of Protein Chemistry* 17(6), 513-514.

Kardum, J.P., Sander, A. & Skansi, D., (2001). Comparison of convective, vacuum, and microwave drying chlorpropamide. *Drying Technology* 19(1), 167-183.

Kim, M.H. & Toledo, R.T., (1987). Effect of osmotic dyhydration and high temperature fluidized bed drying on properties of dehydrated rabbiteye blueberries. *Journal of Food Science* 52(4), 980-984.

King, V.A.E. & Zall, R.R., (1992). A response-surface methodology approach to the optimization of controlled low-temperature vacuum dehydration *Food Research International* 25(1), 1-8.

Kiranoudis, C.T., Tsami, E. & Maroulis, Z.B., (1997). Microwave vacuum drying kinetics of some fruits. *Drying Technology* 15(10), 2421-2440.

Kitts, D.D. & Hu, C., (2005). Biological and chemical assessment of antioxidant activity of sugar-lysine model Maillard reaction products. *Annals of the New York Academy of Sciences* 1043(1), 501-512.

Klewicki, R., Konopacka, D., Uczciwek, M., Irzyniec, Z., Piasecka, E. & Bonazzi, C., (2009). Sorption isotherms for osmo-convectively-dried and osmo-freeze-dried apple, sour cherry, and blackcurrant. *Journal of Horticultural Science & Biotechnology* (ISAFRUIT Special Issue), 75-79.

Kohout, M. & Stepanek, F., (2007). Multi-scale analysis of vacuum contact drying. *Drying Technology* 25(7-8), 1265-1273.

Kompany, E., Benchimol, J., Allaf, K., Ainseba, B. & Bouvier, J.M., (1993). Carrot dehydration for instant rehydration - dehydration kinetics and modeling. *Drying Technology* 11(3), 451-470.

Kraft, T.E.B., Schmidt, B.M., Knight, Y., Cuendet, M., Kang, Y.H., Pezzuto, J.M., Seigler, D.S. & Lila, M.A., (2005). Chemopreventive potential of wild lowbush blueberry fruits in multiple stages of carcinogenesis. *Journal of Food Science* 70(3), S159-S166.

Krewer, G. & NeSmith, D.S., (2002). The Georgia blueberry industry: Its history, present state, and potential for development in the next decade. *Acta Horticulturae* 574, 101-106.

Krokida, M.K., Kiranoudis, C.T. & Maroulis, Z.B., (1999). Viscoelastic behaviour of dehydrated products during rehydration. *Journal of Food Engineering* 40(4), 269-277.

Krokida, M.K., Kiranoudis, C.T., Maroulis, Z.B. & Marinos-Kouris, D., (2000). Drying related properties of apple. *Drying Technology* 18(6), 1251-1267.

Krokida, M.K. & Maroulis, Z.B., (1997). Effect of drying method on shrinkage and porosity. *Drying Technology* 15(10), 2441-2458.

Krokida, M.K. & Maroulis, Z.B., (2000). The effect of drying methods on viscoelastic behaviour of dehydrated fruits and vegetables. *International Journal of Food Science and Technology* 35(4), 391-400.

Krokida, M.K. & Maroulis, Z.B., (2001). Structural properties of dehydrated products during rehydration. *International Journal of Food Science and Technology* 36(5), 529-538.

Krokida, M.K., Maroulis, Z.B. & Saravacos, G.D., (2001). The effect of the method of drying on the colour of dehydrated products. *International Journal of Food Science and Technology* 36(1), 53-59.

Krokida, M.K., Tsami, E. & Maroulis, Z.B., (1998). Kinetics on color changes during drying of some fruits and vegetables. *Drying Technology* 16(3-5), 667-685.

Kumazawa, E., Ido, K., Okazaki, M. & Toei, R., (1984). Vacuum drying of maltodextrin aqueous solution with ethanol in foamed state, *International Drying Symposium*. Society of Chemical Engineers, Kyoto, Japan, pp. 480-486.

Kumazawa, E., Okazaki, M. & Toei, R., (1990). Vacuum-drying of maltodextrin aqueous solutions with ethanol in a foamed state. *Heat Transfer - Japanese Research* 19(7), 697-715.

Kumazawa, E., Saiki, Y., Ido, K. & Okazaki, M., (1991). Development of a continuous vacuum dryer for highly viscous liquid foods. *Heat Transfer - Japanese Research* 20(4), 339-356.

Kwok, B.H.L., Hu, C., Durance, T. & Kitts, D.D., (2004). Dehydration techniques affect phytochemical contents and free radical scavenging activities of Saskatoon berries (*Amelanchier alnifolia* Nutt.). *Journal of Food Science* 69(3), 122-126.

Larrauri, J.A., Ruperez, P. & Saura-Calixto, F., (1997). Effect of drying temperature on the stability of polyphenols and antioxidant activity of red grape pomace peels. *Journal of Agricultural and Food Chemistry* 45(4), 1390-1393.

Latti, A.K., Riihinen, K.R. & Kainulainen, P.S., (2008). Analysis of anthocyanin variation in wild populations of bilberry (*Vaccinium myrtillus* L.) in Finland. *Journal of Agricultural and Food Chemistry* 56(1), 190-196.

Lazarides, H.N. & Mavroudis, N.E., (1996). Kinetics of osmotic dehydration of a highly shrinking vegetable tissue in a salt-free medium. *Journal of Food Engineering* 30(1-2), 61-74.

Lazarus, S.A., Adamson, G.E., Hammerstone, J.F. & Schmitz, H.H., (1999). High-performance liquid chromatography/mass spectrometry analysis of proanthocyanidins in foods and beverages. *Journal of Agricultural and Food Chemistry* 47(9), 3693-3701.

Lee, J., Durst, R.W. & Wrolstad, R.E., (2005). Determination of total monomeric anthocyanin pigment content of fruit juices, beverages, natural colorants, and wines by the pH differential method: Collaborative study. *journal of AOAC International* 88(5), 1269-1278.

Lee, J.H. & Kim, H.J., (2009). Vacuum drying kinetics of Asian white radish (*Raphanus sativus* L.) slices. *Lwt-Food Science and Technology* 42(1), 180-186.

Lefsrud, M., Kopsell, D., Sams, C., Wills, J. & Both, A.J., (2008). Dry matter content and stability of carotenoids in kale and spinach during drying. *Hortscience* 43(6), 1731-1736.

Lin, T.M., Durance, T.D. & Scaman, C.H., (1998). Characterization of vacuum microwave, air and freeze dried carrot slices. *Food Research International* 31(2), 111-117.

Liu, X., Qiu, Z., Wang, L. & Chen, Y., (2011). Quality evaluation of *Panax notoginseng* extract dried by different drying methods. *Food and Bioproducts Processing* 89(1), 10-14.

Liu, X., Qiu, Z., Wang, L., Cheng, Y., Qu, H. & Chen, Y., (2009). Mathematical modeling for thin layer vacuum belt drying of *Panax notoginseng* extract. *Energy Conversion and Management* 50(4), 928-932.

Lohachoompol, V., (2007). Effects of drying on anthocyanins in blueberries. *Food Science and Technology, School of Chemical Sciences and Engineering*. The University of New South Wales, Sydney, Australia.

Lohachoompol, V., Mulholland, M., Srzednicki, G. & Craske, J., (2008). Determination of anthocyanins in various cultivars of highbush and rabbiteye blueberries. *Food Chemistry* 111(1), 249-254.

Lohachoompol, V., Srzednicki, G. & Craske, J., (2004). The change of total anthocyanins in blueberries and their antioxidant effect after drying and freezing. *Journal of Biomedicine and Biotechnology* 2004(5), 248-252.

Lohachoompol, V., Srzednicki, G. & Mulholland, M., (2007). Effects of pre-treatments on drying kinetics and anthocyanin content in dried blueberries, in: Chen, G. (Ed.), *5th Asia-Pacific Drying Conference*, Hong Kong, pp. 1077-1084.

MacGregor, W., (2005). Effects of air velocity, air temperature, and berry diameter on wild blueberry drying. *Drying Technology* 23(1-2), 387-396.

Madamba, P.S. & Liboon, F.A., (2001). Optimization of the vacuum dehydration of celery (*Apium graveolens*) using the response surface methodology. *Drying Technology* 19(3-4), 611-626.

Makus, D.J. & Morris, J.R., (1993). A comparison of fruit of highbush and rabbiteye blueberry cultivars. *Journal of Food Quality* 16(6), 417-428.

Maltini, E., Nani, R. & Bertolo, G., (1992). Role of serum viscosity and of pulp content in the vacuum belt drying of pure fruit juices. *International Journal of Food Science & Technology* 27(5), 531-539.

Manthey, J.A., (2000). Biological properties of flavonoids pertaining to inflammation. *Microcirculation* 7(S1), S29-S34.

Marniemi, J., Hakala, P., Maki, J. & Ahotupa, M., (2000). Partial resistance of low density lipoprotein to oxidation in vivo after increased intake of berries. *Nutrition, Metabolism and Cardiovascular Diseases* 10(6), 331-337.

Mazza, G., (1983). Dehydration of carrots: Effects of pre-drying treatments on moisture transport and product quality. *International Journal of Food Science & Technology* 18(1), 113-123.

Mazza, G. & Brouillard, R., (1987). Recent developments in the stabilization of anthocyanins in food products. *Food Chemistry* 25(3), 207-225.

Mazza, G. & Brouillard, R., (1990). The mechanism of co-pigmentation of anthocyanins in aqueous solutions. *Phytochemistry* 29(4), 1097-1102.

McGuire, R.G., (1992). Reporting of objective colour measurements. *Hortscience* 27(12), 1254-1255.

McMinn, W.A.M., Farrell, G. & Magee, T.R.A., (2007). Prediction of microwave drying behavior of pharmaceutical powders using thin-layer models. *Drying Technology* 25(9), 1551-1569.

Mejia-Meza, E.I., Yanez, J.A., Davies, N.M., Rasco, B., Younce, F., Remsberg, C.M. & Clary, C., (2008). *Improving nutritional value of dried blueberries (Vaccinium corymbosum L.) combining microwave-vacuum, hot-air drying and freeze drying technologies*. Journal 4(5), article 5. Online: http://www.bepress.com/ijfe/vol4/iss5/art5/

Methakhup, S., Chiewchan, N. & Devahastin, S., (2005). Effects of drying methods and conditions on drying kinetics and quality of Indian gooseberry flake. *LWT - Food Science and Technology* 38(6), 579-587.

Moreira, R. & Sereno, A.M., (2003). Evaluation of mass transfer coefficients and volumetric shrinkage during osmotic dehydration of apple using sucrose solutions in static and non-static conditions. *Journal of Food Engineering* 57(1), 25-31.

Moreno, J., Bugueno, G., Velasco, V., Petzold, V. & Tabilo-Munizaga, G., (2004). Osmotic dehydration and vacuum impregnation on physicochemical properties of chilean papay (*Carica candamarcensis*). *Journal of Food Science* 69(3), FEP102-FEP106.

Moyer, R.A., Hummer, K.E., Finn, C.E., Frei, B. & Wrolstad, R.E., (2002). Anthocyanins, phenolics, and antioxidant capacity in diverse small fruits: *Vaccinium*, *Rubus*, and *Ribes*. *Journal of Agricultural and Food Chemistry* 50(3), 519-525.

Naczk, M. & Shahidi, F., (2006). Phenolics in cereals, fruits and vegetables: Occurrence, extraction and analysis. *Journal of Pharmaceutical and Biomedical Analysis* 41(5), 1523-1542.

Nicoue, E.E., Savard, S. & Belkacemi, K., (2007). Anthocyanins in wild blueberries of Quebec: Extraction and identification. *Journal of Agricultural and Food Chemistry* 55(14), 5626-5635.

Nsonzi, F. & Ramaswamy, H.S., (1998a). Osmotic dehydration kinetics of blueberries. *Drying Technology* 16(3-5), 725-741.

Nsonzi, F. & Ramaswamy, H.S., (1998b). Quality evaluation of osmo-convective dried blueberries. *Drying Technology* 16(3-5), 705-723.

Osinskij, V.P., (1994). Drier devices for a variety of applications. *Khimicheskoe I Neftyanoe Mashinostroenie* (10), 7-11.

Pang, W., Jiang, Y., Fang, H., Fang, H. & Liu, J., (2008). Study of nutritional intervention on cognitive impairment in community-dwelling elders. *Acta Nutrimenta Sinica* 30(3), 238-242.

Parada, J. & Aguilera, J.M., (2007). Food microstructure affects the bioavailability of several nutrients. *Journal of Food Science* 72(2), R21-R32.

Pere, C. & Rodier, E., (2002). Microwave vacuum drying of porous media: Experimental study and qualitative considerations of internal transfers. *Chemical Engineering and Processing* 41(5), 427-436.

Prior, R.L., Cao, G.H., Martin, A., Sofic, E., McEwen, J., O'Brien, C., Lischner, N., Ehlenfeldt, M., Kalt, W., Krewer, G. & Mainland, C.M., (1998). Antioxidant capacity as influenced by total phenolic and anthocyanin content, maturity, and variety of Vaccinium species. *Journal of Agricultural and Food Chemistry* 46(7), 2686-2693.

Prior, R.L., Hoang, H., Gu, L.W., Wu, X.L., Bacchiocca, M., Howard, L., Hampsch-Woodill, M., Huang, D.J., Ou, B.X. & Jacob, R., (2003). Assays for hydrophilic and lipophilic antioxidant capacity (oxygen radical absorbance capacity (ORAC(FL))) of plasma and other biological and food samples. *Journal of Agricultural and Food Chemistry* 51(11), 3273-3279.

Prior, R.L., Lazarus, S.A., Cao, G., Muccitelli, H. & Hammerstone, J.F., (2001). Identification of procyanidins and anthocyanins in blueberries and cranberries (Vaccinium spp.) using high-performance liquid chromatography/mass spectrometry. *Journal of Agricultural and Food Chemistry* 49(3), 1270-1276.

Prior, R.L., Wu, X.L., Gu, L.W., Safadi, A. & Cook, R., (2004). Absorption of antioxidants by human subjects following a meal containing either grape (G) or lowbush blueberry (BB) freeze dried powders. *Faseb Journal* 18(4), A517-A517.

Rimando, A.M., Kalt, W., Magee, J.B., Dewey, J. & Ballington, J.R., (2004). Resveratrol, pterostilbene, and piceatannol in *Vaccinium* berries. *Journal of Agricultural and Food Chemistry* 52(15), 4713-4719.

Rodríguez-Saona, L.E., Giusti, M.M. & Wrolstad, R.E., (1999). Color and pigment stability of red radish and red-fleshed potato anthocyanins in juice model systems. *Journal of Food Science* 64(3), 451-456.

Sabarez, H., Price, W.E., Back, P.J. & Woolf, L.A., (1997). Modelling the kinetics of drying of d'Agen plums (*Prunus domestica*). *Food Chemistry* 60(3), 371-382.

Sadik, N.A.H., El-Maraghy, S.A. & Ismail, M.F., (2008). Diethylnitrosamine-induced hepatocarcinogenesis in rats: Possible chemoprevention by blueberries. *African Journal of Biochemistry Research* 2(3), 81-87.

Saftner, R., Polashock, J., Ehlenfeldt, M. & Vinyard, B., (2008). Instrumental and sensory quality characteristics of blueberry fruit from twelve cultivars. *Postharvest Biology and Technology* 49(1), 19-26.

Schmidt, B.M., Erdman, J.W., Jr. & Lila, M.A., (2005). Effects of food processing on blueberry antiproliferation and antioxidant activity. *Journal of Food Science* 70(6), S389-S394.

Schmidt, B.M., Howell, A.B., McEniry, B., Knight, C.T., Seigler, D., Erdman, J.W. & Lila, M.A., (2004). Effective separation of potent anti proliferation and antiadhesion components from wild blueberry (*Vaccinium angustifolium* ait.) fruits. *Journal of Agricultural and Food Chemistry* 52(21), 6433-6442.

Schonherr, J., (1976). Water permeability of isolate cuticular membranes: The effect of cuticular waxes on diffusion of water. *Planta* 131(2), 159-164.

Scibisz, I. & Mitek, M., (2007). The changes of antioxidant properties in highbush blueberries (*Vaccinium corymbosum* L.) during freezing and long-term frozen storage. *Acta Scientiarum Polonorum - Technologia Alimentaria* 6(4), 75-81.

Seeram, N.P., Adams, L.S., Zhang, Y.J., Lee, R., Sand, D., Scheuller, H.S. & Heber, D., (2006). Blackberry, black raspberry, blueberry, cranberry, red raspberry, and strawberry extracts inhibit growth and stimulate apoptosis of human cancer cells in vitro. *Journal of Agricultural and Food Chemistry* 54(25), 9329-9339.

Sellappan, S., Akoh, C.C. & Krewer, G., (2002). Phenolic compounds and antioxidant capacity of Georgia-grown blueberries and blackberries. *Journal of Agricultural and Food Chemistry* 50(8), 2432-2438.

Shi, J., Pan, Z., McHugh, T.H., Wood, D., Zhu, Y., Avena-Bustillos, R.J. & Hirschberg, E., (2008). Effect of berry size and sodium hydroxide pretreatment on the drying characteristics of blueberries under infrared radiation heating. *Journal of Food Science* 73(6), E259-E265.

Shi, X.Q., Fito, P. & Chiralt, A., (1995). Influence of vacuum treatment on mass transfer during osmotic dehydration of fruits. *Food Research International* 28(5), 445-454.

Shishehgarha, F., Makhlouf, J. & Ratti, C., (2002). Freeze-drying characteristics of strawberries. *Drying Technology* 20(1), 131-145.

Singh, B., Bhat, T.K. & Singh, B., (2003). Potential therapeutic applications of some antinutritional plant secondary metabolites. *Journal of Agricultural and Food Chemistry* 51(19), 5579-5597.

Skrede, G., Wrolstad, R.E. & Durst, R.W., (2000). Changes in anthocyanins and polyphenolics during juice processing of highbush blueberries (*Vaccinium corymbosum* L.). *Journal of Food Science* 65(2), 357-364.

Smith, M.A.L., Marley, K.A., Seigler, D., Singletary, K.W. & Meline, B., (2000). Bioactive properties of wild blueberry fruits. *Journal of Food Science* 65(2), 352-356.

Song, C.S., Nam, J.H., Kim, C.J. & Ro, S.T., (2002). A finite volume analysis of vacuum freeze drying processes of skim milk solution in trays and vials. *Drying Technology* 20(2), 283-305.

Stojanovic, J. & Silva, J.L., (2007). Influence of osmotic concentration, continuous high frequency ultrasound and dehydration on antioxidants, colour and chemical properties of rabbiteye blueberries. *Food Chemistry* 101(3), 898-906.

Strumillo, C., Zbicinski, I. & Lui, X.D., (1996). Effect of particle structure on quality retention of bio-products during thermal drying. *Drying Technology* 14(9), 1921-1946.

Sullivan, J.F., Craig, J.C.J., Dekazos, E.D., Leiby, S.M. & Konstance, R.P., (1982). Dehydrated blueberries by the continuous explosion-puffing process. *Journal of Food Science* 47(2), 445-448.

Sunjka, P.S., Orsat, V. & Raghavan, G.S.V., (2008). Microwave/vacuum drying of cranberries (*Vacccinium macrocarpon*). *American Journal of Food Technology* 3(2), 100-108.

Sweeney, M.I., Kalt, W., MacKinnon, S.L., Ashby, J. & Gottschall-Pass, K.T., (2002). Feeding rats diets enriched in lowbush blueberries for six weeks decreases ischemia-induced brain damage. *Nutritional Neuroscience* 5(6), 427-431.

Taherian, A.R., Marcotte, M. & Poirier, M., (2002). Drying of blueberries in fluid and pulsed fluid beds, *Internal Report of Food Research and Development Centre*. Agriculture and Agri-Food Canada, Saint-Hyacinthe, QC, Canada.

Tapia, M.S., Lopez-Malo, A., Consuegra, R., Corte, P. & Welti-Chanes, J., (1999). Minimally processed papaya by vacuum osmotic dehydration (VOD) techniques. *Food Science and Technology International* 5(1), 41-49.

Theocharis, A.D., Tsolakis, I., Tsegenidis, T. & Karamanos, N.K., (1999). Human abdominal aortic aneurysm is closely associated with compositional and specific structural modifications at the glycosaminoglycan level. *Atherosclerosis* 145(2), 359-368.

Torreggiani, D., (1993). Osmotic dehydration in fruits and vegetable processing. *Food Research International* 26(2), 59-68.

Torringa, E., Esveld, E., Scheewe, I., Van Den Berg, R. & Bartals, P., (2001). Osmotic dehydration as a pre-treatment before combined microwave-hot-air drying of mushrooms. *Journal of Food Engineering* 49(2-3), 185-191.

USDA, (2010). U.S. Blueberry Industry. Table 14--Cultivated blueberries: Commercial acreage, yield per acre, production, and season-average grower price in Georgia, 1992-2009, March 2010 ed. USDA Economics, Statistics and Market Information System, Albert R. Mann Library, Cornell University.

USDA, (2011). Noncitrus fruits and nuts: 2010 summary. *National Agricultural Statistics Service*.

Vaghri, Z., Scaman, C.H., Kitts, D.D., Durance, T. & McArthur, D.A., (2000). Quality of the vacuum microwave dried blueberries in terms of color, composition, and antioxidant activity, *12th International Drying Symposium*, paper 318 ed. Elsevier Science, Amsterdam, pp. 1-10.

Vashisth, T., Singh, R.K. & Pegg, R.B., (2011). Effects on drying on the phenolics content and antioxidant activity of muscadine pomace. *LWT - Food Science and Technology* 44(7), 1649-1657.

Velioglu, Y.S., Mazza, G., Gao, L. & Oomah, B.D., (1998). Antioxidant activity and total phenolics in selected fruits, vegetables, and grain products. *Journal of Agricultural and Food Chemistry* 46(10), 4113-4117.

Venkatachalapathy, K., (1998). Combined osmotic and microwave drying of strawberries and blueberries. *Department of Agricultural and Biosystems Engineering*. McGill University, Quebec, Canada.

Venkatachalapathy, K. & Raghavan, G.S.V., (1998). Microwave drying of osmotically dehydrated blueberries. *Journal of Microwave Power and Electromagnetic Energy* 33(2), 95-102.

Viljanen, K., Kylli, P., Kivikari, R. & Heinonen, M., (2004). Inhibition of protein and lipid oxidation in liposomes by berry phenolics. *Journal of Agricultural and Food Chemistry* 52(24), 7419-7424.

Voss, D.H., (1992). Relating colourimeter measurement of plant colour to the royal horticultural society colour chart. *Hortscience* 27(12), 1256-1260.

Wang, H., Cao, G. & Prior, R.L., (1997). Oxygen radical absorbing capacity of anthocyanins. *Journal of Agricultural and Food Chemistry* 45(2), 304-309.

Wang, J., Li, Y.Z., Chen, R.R., Bao, J.Y. & Yang, G.M., (2007a). Comparison of volatiles of banana powder dehydrated by vacuum belt drying, freeze-drying and air-drying. *Food Chemistry* 104(4), 1516-1521.

Wang, J., Renren, C., Gongming, Y. & Yuanzhi, L., (2007b). Introduction to efficient energy-saving continuous vacuum belt dryer. *Transactions of the CSAE* 23(3), 117-120.

Wang, S.Y. & Lin, H.S., (2000). Antioxidant activity in fruits and leaves of blackberry, raspberry, and strawberry varies with cultivar and developmental stage. *Journal of Agricultural and Food Chemistry* 48(2), 140-146.

Weiss, E.I., Lev-Dor, R., Sharon, N. & Ofek, I., (2002). Inhibitory effect of a high-molecular-weight constituent of cranberry on adhesion of oral bacteria. *Critical Reviews in Food Science and Nutrition* 42(Suppl.), 285-292.

Wilford, L.G., Sabarez, H. & Price, W.E., (1997). Kinetics of carbohydrate change during dehydration of d'Agen prunes. *Food Chemistry* 59(1), 149-155.

Wojdylo, A., Figiel, A. & Oszmianski, J., (2009). Effect of drying methods with the application of vacuum microwaves on the bioactive compounds, color, and antioxidant activity of strawberry fruits. *Journal of Agricultural and Food Chemistry* 57(4), 1337-1343.

Wu, X., Cao, G. & Prior, R.L., (2002). Absorption and metabolism of anthocyanins in elderly women after consumption of elderberry or blueberry. *The Journal of Nutrition* 132(7), 1865-1871.

Wu, X.L., Beecher, G.R., Holden, J.M., Haytowitz, D.B., Gebhardt, S.E. & Prior, R.L., (2004). Lipophilic and hydrophilic antioxidant capacities of common foods in the United States. *Journal of Agricultural and Food Chemistry* 52(12), 4026-4037.

Yang, A.P.P., Wills, C. & Yang, T.C.S., (1987). Use of a combination process of osmotic dehydration and freeze-drying to produce a raisin-type lowbush blueberry product. *Journal of Food Science* 52(6), 1651-1653.

Yang, C.S.T. & Atallah, W.A., (1985). Effect of 4 drying methods on the quality of intermediate moisture lowbush blueberries. *Journal of Food Science* 50(5), 1233-1237.

Yongsawatdigul, J. & Gunasekaran, S., (1996). Microwave-vacuum drying of cranberries: Part II. Quality evaluation. *Journal of Food Processing and Preservation* 20(2), 145-156.

Yue, X. & Xu, Z., (2008). Changes of anthocyanins, anthocyanidins, and antioxidant activity in bilberry extract during dry heating. *Journal of Food Science* 73(6), C494-C499.

CHAPTER 2

VACUUM-BELT DRYING OF FRESH RABBITEYE BLUEBERRIES (*Vaccinium ashei* 'Brightwell'): INFLUENCE OF DRYING CONDITIONS ON MOISTURE PROPERTIES[1]

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Abstract

Rabbiteye blueberries (*Vaccinium ashei* 'Brightwell') were vacuum belt dried using a split-split plot experimental design with three conduction temperatures from 90 to 130 °C, two radiation temperatures from 100 to 120 °C, three drying times from 90 to 120 min, two size categories with and without mechanical skin abrasion to study the influence of the processing variables on the final moisture properties of the blueberries. At the end of drying, moisture content and water activity were measured. The results showed that smaller blueberries dried faster than larger blueberries although skin abrasion was more effective on large blueberries. Mechanical skin abrasion decreased drying time along with higher conduction and radiation temperatures.

2.1 Introduction

Blueberries are an important commercial fruit in the United States, Canada and Europe, with emerging markets in South America, Australia, New Zealand and South Africa (2002). There has been renewed interest in blueberries as numerous studies have indicated their potential health benefits, particularly as related to memory and cognition, cancer prevention, cardiovascular disease, urinary tract infections and health vision (Camire, 2000). Most of this research has focused on the anthocyanins, flavonols, pterostilbene and dietary fiber contained in blueberries.

Blueberries do have a limited growing season and can be stored refrigerated for 4-6 weeks. The limited shelf life results in much fruit being preserved by freezing, heating, and drying. Of the 245 million pounds produced in the U.S., approximately 165 million pounds are further processed (USDA, 2011). Of these, about half are individually quick frozen, while others are processed into pie fillings, juices, jams and jellies, baked goods, snack foods, intermediate and low moisture dried fruit, extracts and dried powders. Drying is a good means of preserving fruit as it lowers the water activity (a_w) to a point that limits microbial growth and chemical changes. It also offers the advantages of reducing transportation weight, eliminating the expense of frozen storage, and allowing opportunities for developing value-added products. Intermediate moisture fruits have an a_w between 0.65 and 0.9, and may be suited for direct consumption, while low moisture fruit (a_w<0.6) are suited for dry powders or fruit to be incorporated in dry mixes.

One disadvantage to drying is that it may promote browning in the product and loss of total phenolics and anthocyanin compounds. This is incurred particularly where higher temperature is applied to promote heat transfer (Kechinski et al., 2010). Thus, freeze-drying is typically used when minimal changes in color or phytochemicals are desired. It is often used to

prepare samples prior to HPLC and other analytical procedures (Prior et al., 2001), and studies have shown that freeze dried blueberry extracts maintain their bioactive properties (Smith et al., 2000). It can be used to produce whole fruit intended to be rehydrated or as a step in the production of powders. However, freeze-drying is typically a batch process and drying times can be fairly long. Spray drying has been used to make blueberry powders from juice concentrates with a good production rate. These usually need to be prepared with a carrier and free-flowing agent to prevent excessive stickiness. While acceptable quality powders may be produced, Biswas (2007) found that only 22-52 % of the original phenolics and anthocyanins are maintained in the process.

Most commercially dried blueberries are osmotically dehydrated with sugar and then hot air dried to a desired moisture content (MC), usually around 12-18 % wet basis (wb). Pretreatments by scarifying or disrupting the waxy epidermal layer can help decrease the drying time by promoting better mass transfer of water (Lohachoompol et al., 2007). While resulting in flavorful berries, both the initial infusion step and heating result in a decrease in bioactive compounds. For example, when dried at 90 °C the total anthocyanin content of highbush blueberries decreased from 7.2 to 4.3 mg/g. Those that had been previously treated in 60 % sucrose/1 % NaCl had even lower values (3.7 mg/g). This likely results as anthocyanins and other phytochemicals are leached into the immersion medium. While several studies have been conducted on sugar-infused blueberries, little information exists on blueberries dried without infusion (MacGregor, 2005). A need for drying methods without sugar infusion exists as the market for fruits dried without added sugar continues to grow.

Several new technologies have developed which may be promising to blueberry drying. A radiant zone dryer was used to produce blueberry powders from extract, juice and purees

(Chakraborty et al., 2009). The liquids were deposited on a moving belt and moved through five temperature zones maintained at 45-90 °C by a series of radiant heaters. After drying, no significant changes were noted in total anthocyanins or total phenolics as compared to the wet starting ingredients. Another approach is to apply drying under vacuum. While this can significantly reduce the drying temperature, it is a batch process and the lack of continuous production can result in an expensive product (Beaudry et al., 2004). A continuous vacuum belt drying system has improved on this, by allowing the product to be introduced under an air-lock, travel under vacuum along a belt that sits over conductive heaters or under radiant heaters, and can be scraped off and collected (Figure 2.1). Drying under vacuum has the additional benefit of limiting browning and other degradation reactions that depend on oxygen.

The objective of this study was to investigate the use of continuous vacuum belt drying to prepare dried whole blueberries to different moisture levels. This involved determining the impact of different factors on drying including blueberry size, physical pretreatment (skin abrasion), conduction temperature, radiation temperature, and time.

2.2 Materials & Methods

Rabbiteye blueberries (*Vaccinium ashei* 'Brightwell') were machine harvested in Alma, Georgia. Fresh blueberries were stored in boxes at 4 °C no more than 21 days after harvesting.

2.2.1 Sizing

Blueberries were categorized by size using a 3 gauge steel plate screen with 12.7 mm diameter perforations. Blueberries 12.7 mm or smaller diameter that passed through the openings were labeled as "small" while those greater than 12.7 mm diameter, remaining on top of the screen, were labeled as "large".

2.2.2 Skin Abrasion Pretreatment

Prior to drying, pre-weighed blueberries (~50 g) were removed from refrigeration and pretreated by mechanical skin abrasion as described by Lohachoompol (2007). Blueberries were placed into a cylindrical container constructed of PVC pipe (19 cm long by 8.9 cm wide) with medium grain 100 grit sand paper glued to the inside wall. PVC threaded caps were used on the ends for easy opening and closing. The berries were rotated on a Clausing lathe (Atlas Press Co., Kalamazoo, MI) calibrated to 100 rotations per minute. Blueberry samples were abraded for 2 min such that the waxy outer layer was removed with minimal pigment bleeding.

2.2.3 Drying

Blueberries were dried in a 0.2 m^2 area laboratory-scale vacuum belt dryer (Model: Zwag LKM-101, Zschokke Wartmann, Ltd., Bucher, Döttingen, Switzerland) with a 20.3 cm wide Teflon coated fiberglass belt passing directly over three bottom plate conduction heating zones and one cooling zone. A radiation plate (22.9 cm wide), designated as Heat Zone 4, with adjustable height (set at 4.7 cm) from the conduction plates expanded the length of all three conduction plates, designated as Heat Zones 1, 2 and 3 (Figure 2.1). The vacuum was pulled using a DVT AquaSeal 80 CFM vacuum pump (Michigan City, IN) and held at < 3.6 kPa throughout drying. The temperatures were set using an integrated touch screen panel and programmable logic controller.

Each drying run included three 50 g batches of fresh blueberries, previously sized, and with or without abrasion. Blueberries were spread on to the belt. A drying run was limited to one top plate radiation temperature and one drying time period. Treatment combinations were randomly determined for radiation temperature (RT), conduction temperature (CT), drying duration (DT), blueberry size (S), and abrasion (Ab). Levels of each factor are listed in Table

2.1. After drying, the blueberries were removed from the chamber, placed into plastic a_w cups, and sealed in moisture-proof containers for 24 to 48 h prior to moisture property measurements.

2.2.4 Moisture content

The moisture content of fresh and dried blueberries was determined using a modified AOAC Method 934.06 (AOAC International, 1995). Five blueberries were cut in half using a razor blade, then weighed into pre-dried aluminum weighing dishes. Samples were placed in a Model 1430MS vacuum oven (VWR International, West Chester, PA) and left at 70°C and 40 kPa for 24 h or until constant mass was achieved. Moisture content was determined in triplicate per drying batch.

2.2.5 Water Activity

Five blueberries (either dried or undried) were cut in half and placed in a sample a_w cup. The a_w of blueberries was measured in an AquaLab Model CX-2 meter (Decagon Devices Inc, Pullman, WA) at 25°C. a_w measurements were performed in triplicate.

2.2.6 Statistical Analysis

A completely randomized split-split plot design was used to examine the effects of multiple factors (DT, CT, RT, S, and Ab) on MC and a_w. Split plots are used when a completely random design cannot be obtained. In this design, there were three stages of randomization: the levels of time were randomized to the whole plots within each block; the levels of RT were randomized to the split-plots within each whole plot of every block; and the rest of the factors (CT, S, and Ab) were randomized to the split-split plots such that a drying run corresponded to one drying time under one RT with any three combinations of size, abrasion, and CT. Twenty-four drying runs resulted in seventy-two treatment batches. Three replications of randomization and drying were performed totaling 216 drying batches (72 treatments replicated three times).

All results were analyzed using ANOVA procedures in SAS 9.1. Both linear and quadratic interactions were analyzed.

2.3 Results & Discussion

Drying simultaneously combines the transfer of heat, mass, and momentum by increasing the temperature of a product so that moisture evaporates into an unsaturated gaseous phase (Rizvi, 1995). The type of internal moisture movement influenced by the food structure determines how long the constant-rate drying period lasts (Rizvi, 1995). Under vacuum moisture diffusing to the surface by capillary and vapor actions is quickly removed from the surface due to the boiling point decrease (Ernst et al., 1938). As several studies have shown (Arevalo-Pinedo & Murr, 2007), the level of vacuum influences dry rates under most conditions with greater vacuum increasing drying rate. Vacuum, averaging 3.6 kPa with slight variations, was not varied due to the number of other factors being studied. The impacts of conduction temperature, radiation temperature, drying time, blueberry size, and abrasion of the blueberry skin on MC and a_w of dried blueberries were explored using a completely random split-split plot statistical design.

Moisture properties from the drying trials are shown in Table 2.2. The different levels of time, conduction temperature, radiation temperature and pretreatment yielded dried blueberries with a variety of MC and a_w values. The initial MC of the fresh rabbiteye blueberries was 83.5 % with a corresponding a_w of 0.990. The MC of the dried blueberries ranged from 60.3 % for large, non-abraded blueberries dried for 90 min at CT = 90 °C and RT = 100 °C down to 0.9 % for small blueberries dried for 120 min at CT = 130 °C and RT = 120 °C. Drying for 90 min with CT = 90 °C and RT = 100 °C represented the shortest drying time and lowest temperature combination, while drying for 120 min at CT = 130 °C and RT = 120 °C represented the longest time and highest temperature combination. Similarly, average a_w values ranged from 0.945 for

large, non-abraded blueberries dried for 90 min with CT = 90 °C and RT = 100 °C down to 0.286 for large, abraded blueberries dried 120 min with CT = 130 °C and RT = 100 °C. Small blueberries dried 90 min with RT = 120 °C and CT = 130 °C had an average a_w of 0.341. Depending on drying conditions, the system was able to prepare blueberries with a range of MC, some suitable as ready-to-eat intermediate moisture foods, some quite dry and more suitable for dry mixes or subsequent grinding into powders.

Commercially dried blueberries range in moisture level from 2-18 % (wb) and can take 12-72 hours to dry depending on whether hot air dried, freeze-dried, or drum-dried (Feng et al., 1999). The vacuum drying method yielded very low moisture (2.2-3.8 %) product within 105-120 minutes depending on conduction and radiation temperatures. This is significantly faster than very low moisture blueberries attained by freeze-drying. Substantially shorter drying times are attained as the vacuum reduces the boiling point of water in the product, resulting in a greater temperature difference between the heating medium and the product. In addition, the vacuum/condenser system helps remove moisture from the vicinity of the product resulting in a greater vapor pressure difference, and causes relatively higher internal pressure that encourages moisture migration to the surface (Perre & Turner, 2006).

The split-split plot ANOVA results, displayed in Table 2.3, show the significant factor and interaction affects on a_w and MC of vacuum-belt dried blueberries. Optimized drying conditions ideally minimize drying time while producing the best desired qualities in dried blueberries, but different characteristic optimization can lead to different optimized processing conditions (Chen et al., 2001). These factors are examined below.

2.3.1 Time as a Factor

Time was a significant factor determining MC and a_w, and the response was linear in both cases (Table 2.3).

A significant linear trend without a significant quadratic trend indicates constant rate drying, while a significant quadratic trend without a significant linear trend indicates falling rate drying. Due to significant linear ($p<0.0001$) and quadratic ($p=0.019$) trends across vacuum drying time for MC, determination of constant rate or falling rate drying was inconclusive. There was a significant quadratic trend for MC, most likely due to samples reaching minimal MC after 120 min of drying (2.9 % at 120 min and CT = 130 °C and 8.1 % at 120 min and CT = 110 °C). Most agricultural drying occurs during the falling rate period (Henderson et al., 1997; Lee & Kim, 2009; Wu et al., 2007) although Li et al. (2008) reported both constant and falling rate drying periods during vacuum drying of wood correlating to steady internal sample temperature during constant rate drying and increasing internal sample temperature during falling rate drying.

The interaction between drying time (90, 105, and 120 min) and radiation temperature (100 and 120 °C) was not significant for a_w or MC, suggesting that the effects of radiation temperature was independent of drying time. The effect of drying time on a_w and MC at radiation temperatures of 100 and 120 °C are shown in Figure 2.2.

The interaction between time and size was significant for MC but not for a_w. This suggests that the a_w at each time did not vary between the large and small blueberries. On the other hand, the MC of large blueberries was greater than the small blueberries at 90 min and 120 min but not 105 min (Figure 2.2b). More specifically, the Size*QuadTime interaction was significant for MC while the Size*LinTime interaction was not. This indicates that the quadratic time trend for MC varied between the large and small blueberries (Figure 2.2b). The whole plot

quadratic trend across time was not significant at the 5 % level, which did not consider the influence of size, CT, RT, or abrasion, but the quadratic trend across time was significant within blueberry size, demonstrating the importance of analyzing component interactions and subsequent trends.

The time*abrade interaction was significant, indicating that a_w and MC at the different drying times varied between abraded and non-abraded blueberries. The quadratic trend across drying time differed depending on the abrasion treatment for both MC and a_w (Figure 2.2). At 90 min, the abraded blueberries exhibited a lower a_w (0.662) than non-abraded blueberries (0.717). The a_w for non-abraded berries decreased more between 90 to 105 min (0.717 to 0.552) as compared to abraded berries (0.662 to 0.557), and less between 105 to 120 min (0.552 to 0.506) as compared to abraded berries (0.557 to 0.424). The difference between treatments suggests that the abrasion disrupted the outer waxy epidermal layer of the blueberry allowing improved moisture removal from the blueberry surface. Lohachoompol (2007) reported that abrasion of the blueberry skin reduced drying time more effectively than osmotic dehydration. Similar results were noted for MC. Non-abraded blueberries had 33.3 % moisture at 90 min, 17.1 at 105 min, and 13.8 at 120 min while abraded blueberries had 23.7 % moisture at 90 min, 16.8 % at 105 min, and 8.0 % at 120 min.

2.3.2 Radiation Temperature as a Factor

Radiation heating occurs via electromagnetic waves transferring energy and aides in quick and uniform heating (Welti-Chanes et al., 2003). In the vacuum-belt dryer, the radiation plate was directly above the three conduction plates and thus assisted in drying the blueberries. Without the radiation heating plate, blueberries exhibited case hardening and did not dry well, supporting the importance of using the radiation plate to assist in drying. Increasing the radiation

temperature from 100 to 120 °C increased the drying rate, as evidenced by lower a_w and MC values. At RT = 120 °C the average a_w was 0.522 while at RT = 100 °C it was 0.615. The average MC of blueberries at RT = 120 °C was also lower (14.5 %) than at RT = 100 °C (22.4 %).

As the vacuum-belt drying implements two types of heat transfer, conduction and radiation, the interaction between conduction temperature and radiation temperature was expected to be significant. The CT*RT interaction was indeed significant for both a_w and MC. Figure 2.3 shows the effect of conduction temperature on a_w and MC, at different RT, size and pretreatment. Higher RT increased the drying rate at a given CT. The average a_w at CT = 90 °C and RT = 100 °C was 0.829 while the a_w at CT = 90°C and RT = 120 °C was 0.715. Similar dependence was found at CT = 110 °C, with an average a_w of 0.602 at RT = 100 °C and 0.469 at RT = 120 °C. Likewise, at CT = 130 °C the average a_w was 0.413 at RT = 100 °C and 0.381 at RT = 120 °C.

Both linear and quadratic CT*RT interactions were significant for a_w, but only the linear interaction was significant for MC. Higher radiation temperature decreased drying time by increasing the removal of moisture from the surface of the blueberry. Figure 2.3b illustrates the decrease in MC as CT increased for RT100 °C (41.0 % at CT = 90 °C, 19.3 % at CT = 110 °C, and 6.8 % at CT = 130 °C) and for RT120 °C (28.6 % at CT = 90 °C, 10.6 % at CT = 110 °C, and 4.5 % at CT = 130 °C).

The interaction abrasion*RT was significant for MC but not a_w. Non-abraded berries had higher a_w and MC values than abraded berries, while samples dried at RT = 100 °C had higher a_w and MC than those at RT = 120 °C. Average a_w values were 0.646 for non-abraded blueberries dried at RT = 100 °C and 0.532 at RT = 120 °C. For abraded blueberries average a_w was 0.584 at

RT = 100 °C and 0.511 at RT = 120 °C. Average MC was 25.5 % for non-abraded blueberries dried at RT = 100 °C and 15.9 % at RT = 120 °C; for abraded blueberries MC was 19.2 % at RT = 100 °C and 13.2 % at RT = 120 °C.

2.3.3 Conduction Temperature as a Factor

Conductive heat transfer occurred by direct contact of the blueberries with heated stainless steel plates covered by the fiberglass belt. Conduction temperatures from 90 to 120 °C affected both a_w and MC of blueberries dried 90 to 120 min. Further analysis showed that both linear and quadratic models could describe the dependence of a_w and MC on CT. It should be noted that substantial darkening occurred for blueberries dried at the longest time and highest CT (120 min at CT = 130 °C). These samples had very low a_w (0.341) and MC (2.9 %).

The Fourier-Biot Law indicates that the conductive heat transfer rate over time is proportional to the temperature gradient. Therefore, a significant interaction was expected between CT and drying time. Further analysis showed a significant interaction between CT*time. Figure 2.4 shows contour plots of MC and a_w for the different combinations of drying time and CT. The slope of a_w and MC across CT differed at each drying time while the slope across time differed at each CT level (Figure 2.4). This indicated a different drying rate for each CT, illustrated in Figure 2.5.

There was no interaction between CT and size for either a_w or MC. Figure 2.3a shows that large blueberries had an average a_w of 0.770, 0.543, and 0.422 at CT = 90, 110 and 130 °C, respectively, while small berries had values of 0.759, 0.529, and 0.386 at those temperatures. The a_w difference between the sizes became most evident at the highest CT (130 °C). The smaller berries had greater surface/volume ratio, allowing easier surface evaporation and greater heat and moisture transfer within the blueberry to the surface.

2.3.4 Size as a Factor

Although basic heat and mass transfer considerations would suggest that size would impact drying time, few studies have looked at the importance of blueberry size on drying. Small blueberries had lower MC and a_w than the large blueberries dried under similar conditions. There was no significant interaction effect between blueberry size and RT, indicating that size and RT had independent effects on blueberry drying. MacGregor (2005) noted that size can have an impact on blueberry drying time in air-drying, but did not directly study this effect, but rather focused on the effects of increased air velocity on large blueberries.

There was an interaction between size and abrasion. Thus, a difference in MC difference in MC existed across the four combinations: small-non-abraded (18.4 %), small-abraded (16.0 %), large-non-abraded (23.1 %), and large-abraded (16.4 %). The large-non-abraded berries also had a greater final a_w compared other combinations. This is expected as larger berries dry slower than smaller berries due to lower surface/volume ratio, coupled with the greater resistance to moisture transfer with the waxy cuticle layer intact. Abrasion on the large blueberries yielded MC values similar to the small blueberries. Since abrasion did not appear to substantially reduce a_w or MC in the small blueberries, abrasion may be better suited for larger berries.

2.3.5 Abrasion as a Factor

Mechanical skin abrasion, resulting in the removal or alteration of the waxy cuticle epidermal layer, was proposed as an alternative to osmotic pre-treatments (Lohachoompol, 2007). Abrasion significantly decreased drying time (Figure 2.2). These results support the findings that mechanical skin abrasion of blueberries and plums decreased drying time (Cinquanta et al., 2002; Di Matteo et al., 2002; Lohachoompol et al., 2007).

2.3.6 Higher Order Interactions

Significant higher order interaction effects indicate multiple relationships exist between several factors. Interaction effects between two factors can be great enough to influence the significance of higher order interactions. The interaction between CT, RT, and time was a higher order interaction for both a_w and MC. All three factors along with the interactions between CT-time and CT-RT were significant.

2.4 Conclusions

Vacuum belt drying is a continuous drying technique that can produce dried product in shorter times than hot air or freeze-drying. Mechanical skin abrasion of fresh blueberries significantly increased the drying rate with a greater impact on larger blueberries. Small blueberries had lower MC and a_w than large blueberries at a given drying time. MC and a_w of blueberries decreased with drying time allowing for a range of intermediate and low moisture fruit. Analyzing component trends and interactions yielded additional information. The conditions studied yielded dried blueberries with a variety of a_w and MC values, establishing a starting point for future blueberry drying experiments.

References

(2002). *Blueberries*. U.S. Highbush Blueberry Council.(August 17, 2009). Online: http://www.blueberry.org/blueberries.htm

AOAC International, (1995). *Official Methods of Analysis* (16th ed). Association of Official Analytical Chemists International, Arlington, Virginia.

Arevalo-Pinedo, A. & Murr, F.E.X., (2007). Influence of pre-treatments on the drying kinetics during vacuum drying of carrot and pumpkin. *Journal of Food Engineering* 80(1), 152-156.

Beaudry, C., Raghavan, G.S.V., Ratti, C. & Rennie, T.J., (2004). Effect of four drying methods on the quality of osmotically dehydrated cranberries. *Drying Technology* 22(3), 521-539.

Biswas, R., (2007). Development of technologies for the production of polyphenolic nutraceuticals from muscadine grapes and rabbiteye blueberries. *Food Science and Technology*. University of Georgia.

Camire, M.E., (2000). Bilberries and blueberries as functional foods & pharmaceuticals., in: Mazza, G. & Ooomah, B.D. (Eds.), *Functional foods: herbs, botanicals and teas*. Technomic Press, Lancaster, Pa, pp. 289-319.

Chakraborty, M., Savarese, M., Harbertson, E., Harbertson, J. & Ringer, K.L., (2009). Effect of the novel radiant zone drying method on anthocyanins and phenolics of three blueberry liquids. *Journal of Agricultural and Food Chemistry* 58(1), 324-330.

Chen, C.R., Ramaswamy, H.S. & Alli, I., (2001). Prediction of quality changes during osmo-convective drying of blueberries using neural network models for process optimization. *Drying Technology* 19(3-4), 507-523.

Cinquanta, L., Di Matteo, M. & Esti, M., (2002). Physical pre-treatment of plums (*Prunus domestica*). Part 2. Effect on the quality characteristics of different prune cultivars. *Food Chemistry* 79(2), 233-238.

Di Matteo, M., Cinquanta, L., Galiero, G. & Crescitelli, S., (2002). Physical pre-treatment of plums (*Prunus domestica*). Part 1. Modelling the kinetics of drying. *Food Chemistry* 79(2), 227-232.

Ernst, R.C., Ridgway, J.W. & Tiller, F.M., (1938). Practical vacuum drying. *Industrial & Engineering Chemistry* 30(10), 1122-1125.

Feng, H., Tang, J.M., Mattinson, D.S. & Fellman, J.K., (1999). Microwave and spouted bed drying of frozen blueberries: The effect of drying and pretreatment methods on physical properties and retention of flavor volatiles. *Journal of Food Processing and Preservation* 23(6), 463-479.

Henderson, S.M., Perry, R.L. & Young, J.H., (1997). *Principles of process engineering* (4th Edition ed). ASAE, USA.

Kechinski, C.P., Guimaraes, P.V.R., Norena, C.P.Z., Tessaro, I.C. & Marczak, L.D.F., (2010). Degradation kinetics of anthocyanin in blueberry juice during thermal treatment. *Journal of Food Science* 75(2), C173-C176.

Lee, J.H. & Kim, H.J., (2009). Vacuum drying kinetics of Asian white radish (*Raphanus sativus* L.) slices. *Lwt-Food Science and Technology* 42(1), 180-186.

Li, X.J., Zhang, B.G. & Li, W.J., (2008). Microwave-vacuum drying of wood: Model formulation and verification. *Drying Technology* 26(11), 1382-1387.

Lohachoompol, V., (2007). Effects of drying on anthocyanins in blueberries. *Food Science and Technology, School of Chemical Sciences and Engineering*. The University of New South Wales, Sydney, Australia.

Lohachoompol, V., Srzednicki, G. & Mulholland, M., (2007). Effects of pre-treatments on drying kinetics and anthocyanin content in dried blueberries, in: Chen, G. (Ed.), *5th Asia-Pacific Drying Conference*, Hong Kong, pp. 1077-1084.

MacGregor, W., (2005). Effects of air velocity, air temperature, and berry diameter on wild blueberry drying. *Drying Technology* 23(1-2), 387-396.

Perre, P. & Turner, I.W., (2006). A dual-scale model for describing drier and porous medium interactions. *Aiche Journal* 52(9), 3109-3117.

Prior, R.L., Lazarus, S.A., Cao, G., Muccitelli, H. & Hammerstone, J.F., (2001). Identification of procyanidins and anthocyanins in blueberries and cranberries (Vaccinium spp.) using high-performance liquid chromatography/mass spectrometry. *Journal of Agricultural and Food Chemistry* 49(3), 1270-1276.

Rizvi, S.S.H., (1995). Thermodynamic properties of foods in dehydration, in: Rao, M.A. & Rizvi, S.S.H. (Eds.), *Engineering Properties of Foods*, 2nd ed. Marcel Dekker, Inc., New York, pp. 223-309.

Smith, M.A.L., Marley, K.A., Seigler, D., Singletary, K.W. & Meline, B., (2000). Bioactive properties of wild blueberry fruits. *Journal of Food Science* 65(2), 352-356.

USDA, (2011). Noncitrus fruits and nuts: 2010 summary. *National Agricultural Statistics Service*.

Welti-Chanes, J., Velez-Ruiz, J.F. & Barbosa-Canovas, G.V., (2003). Transport phenomena in food processing, in: Barbosa-Canovas, G.V. (Ed.), *Food preservation technology series*. CRC Press, New York, p. 545.

Wu, L., Orikasa, T., Ogawa, Y. & Tagawa, A., (2007). Vacuum drying characteristics of eggplants. *Journal of Food Engineering* 83(3), 422-429.

Figures and Tables

Table 2.1 Experimental factors and levels comprising treatment combinations.

Factor (units)	Factor (abbreviation)	Levels		
Drying Time (minutes)	DT	90	105	120
Conduction Temperature (°C)	CT	90	110	130
Radiation Temperature (°C)	RT	100	120	
Blueberry Size	S	Small	Large	
Abrasion	Ab	Non-Abraded	Abraded	

Table 2.2 Average MC and a_w values of vacuum belt dried blueberries for each combination of conduction temperature, radiation temperature, and drying time.

Radiation Temperature (°C)	Conduction Temperature (°C)	Time (min)	MC avg±stdev (%)	a_w avg±stdev
100	90	90	49 ± 12	0.905 ± 0.055
		105	42 ± 15	0.852 ± 0.110
		120	32 ± 19	0.740 ± 0.207
	110	90	31 ± 15	0.759 ± 0.162
		105	17 ± 12	0.582 ± 0.200
		120	11 ± 11	0.473 ± 0.185
	130	90	16 ± 13	0.577 ± 0.205
		105	2.9 ± 5.0	0.352 ± 0.104
		120	1.5 ± 1.8	0.312 ± 0.044
120	90	90	43 ± 13	0.867 ± 0.087
		105	30 ± 13	0.767 ± 0.125
		120	13 ± 14	0.517 ± 0.221
	110	90	20 ± 14	0.627 ± 0.200
		105	6.7 ± 9.6	0.410 ± 0.158
		120	5.0 ± 5.8	0.370 ± 0.111
	130	90	5.9 ± 7.3	0.398 ± 0.134
		105	3.8 ± 6.2	0.364 ± 0.116
		120	3.7 ± 7.0	0.370 ± 0.132

Table 2.3 Split-split plot ANOVA table for the water activity and moisture content of vacuum belt dried blueberries.

Source	df	a_w p value	MC p value
Whole Plot			
Time (DT)	2	<0.0001	<0.0001
Linear Time	1	<0.0001	<0.0001
Rep	8	<0.0001	0.0006
Error Whole Plot	16		
Split Plots			
RT	1	<0.0001	<0.0001
Error Split Plots	24		
Split-Split Plots			
CT	2	<0.0001	<0.0001
Lin CT	1	<0.0001	<0.0001
Quad CT	1	<0.0001	<0.0001
CT*Time	1	<0.0001	<0.0001
LinCT*LinT	1	0.0006	<0.0001
LinCT*QuadT	1	<0.0001	0.017
QuadCT*LinT	1	0.012	0.462
QuadCT*QuadT	1	0.013	0.030
CT*RT	2	0.0002	<0.0001
RT*LinCT	1	0.001	<0.0001
RT*QuadCT	1	0.007	0.417
CT*RT*DT	4	<0.0001	<0.0001
Size	1	0.019	0.0009
Size*DT	2	0.175	0.027
Size*QuadT	1	0.08	0.008
Abrade	1	<0.0001	<0.0001
Abrade*DT	2	0.001	0.0003
Abrade*QuadT	1	0.0005	<0.0001
Abrade*RT	1	0.016	0.024
Abrade*Size	1	0.089	0.008
Error Split-Split Plots	528		
Total	647		

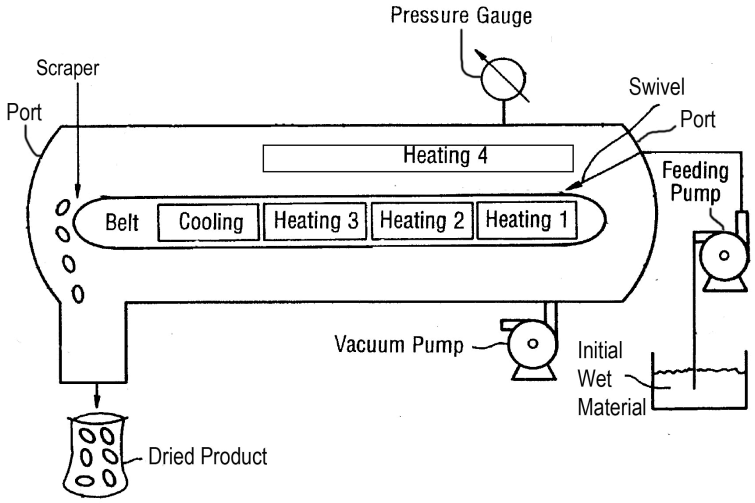
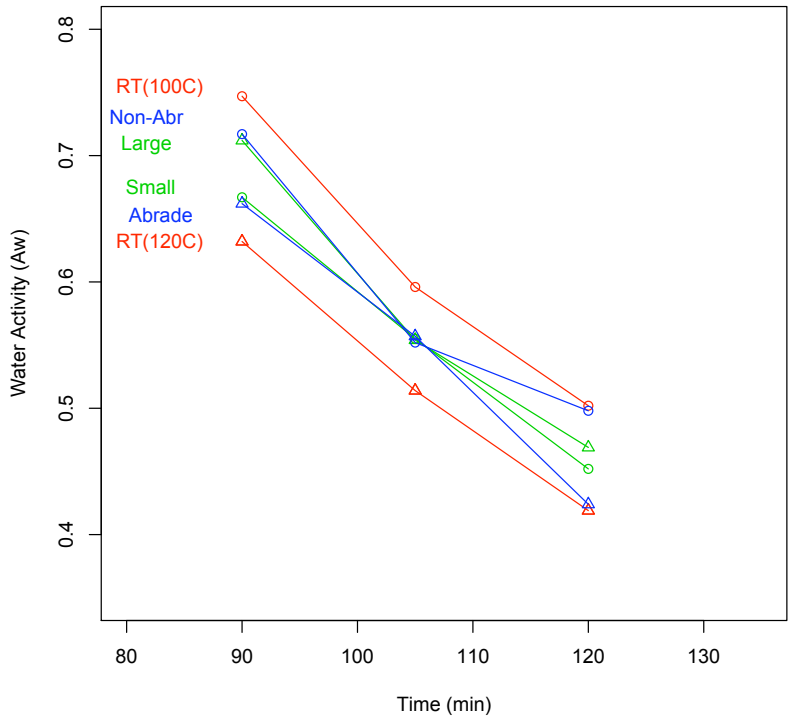
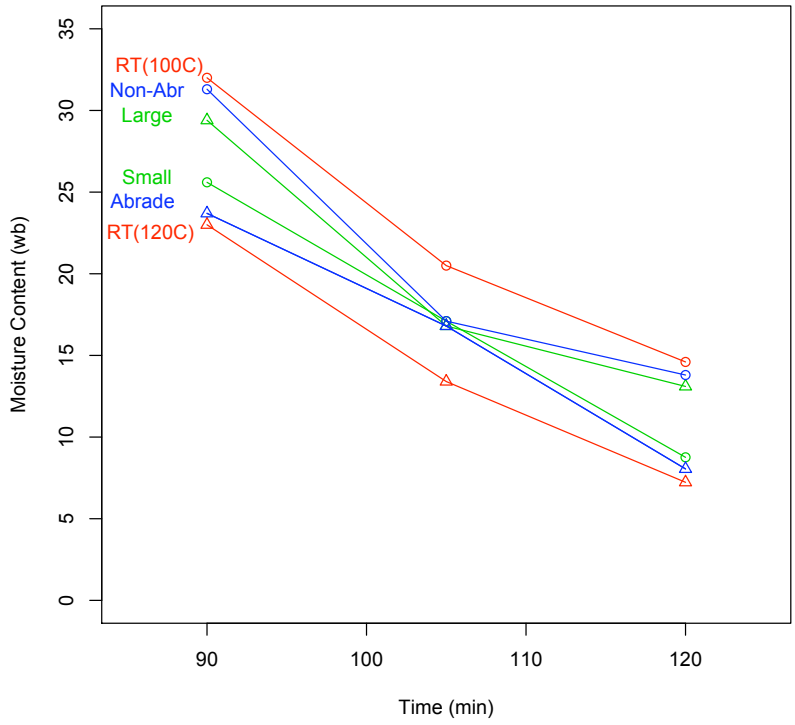


Figure 2.1 Schematic of experimental continuous vacuum belt dryer.

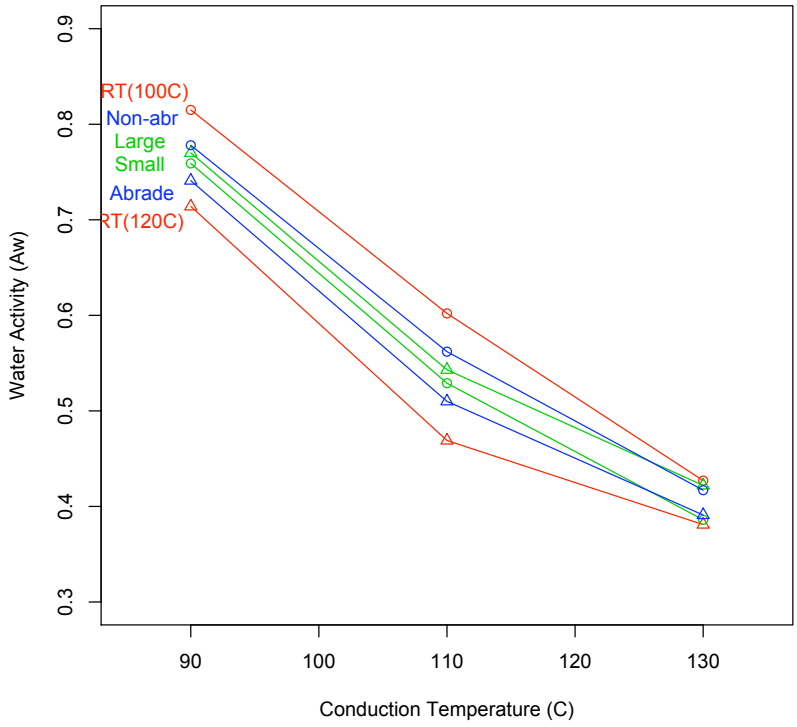


(a)

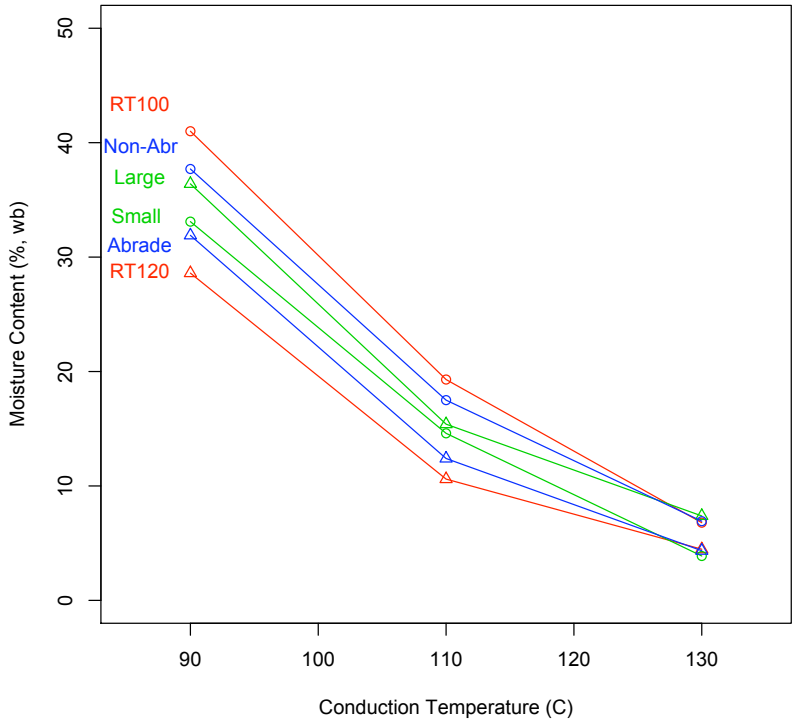


(b)

Figure 2.2 Effect of size, mechanical abrasion, and radiation temperature on (a) a_w and (b) MC of vacuum belt dried blueberries as a function of drying time.

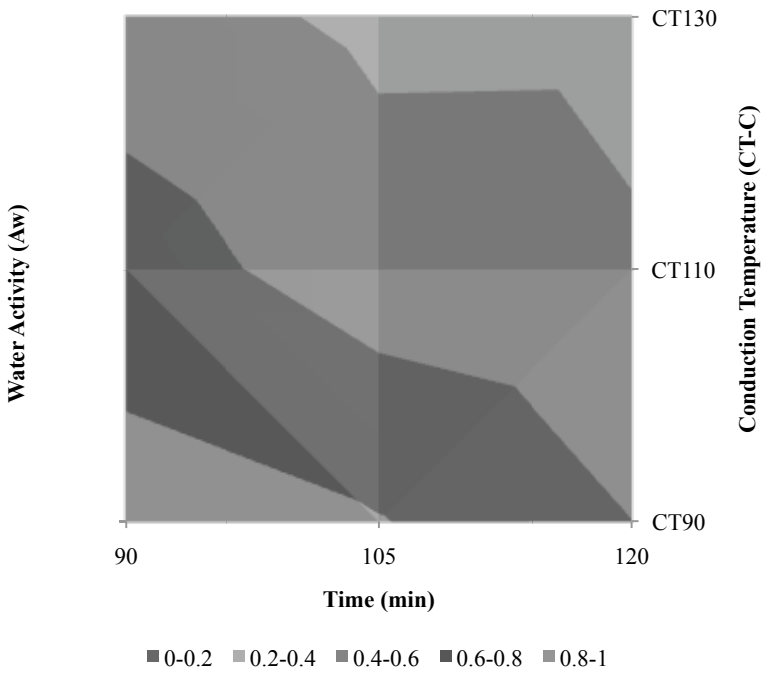


(a)

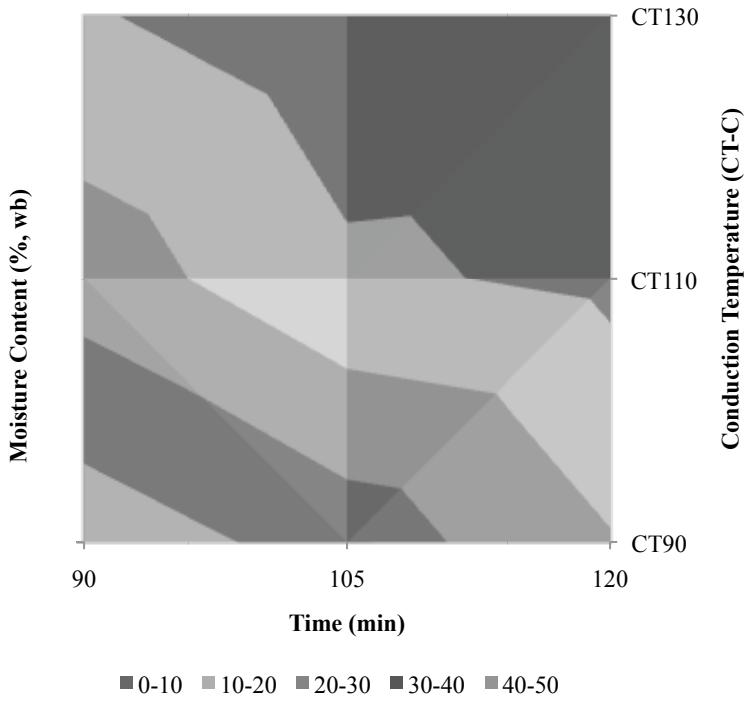


(b)

Figure 2.3 Effects of size, mechanical abrasion, and radiation temperature on (a) a_w and (b) MC of vacuum belt dried blueberries as a function of conduction plate temperature.



(a)



(b)

Figure 2.4 Contour plots for (a) a_w and (b) MC of vacuum belt dried blueberries as a function of drying time and conduction temperature.

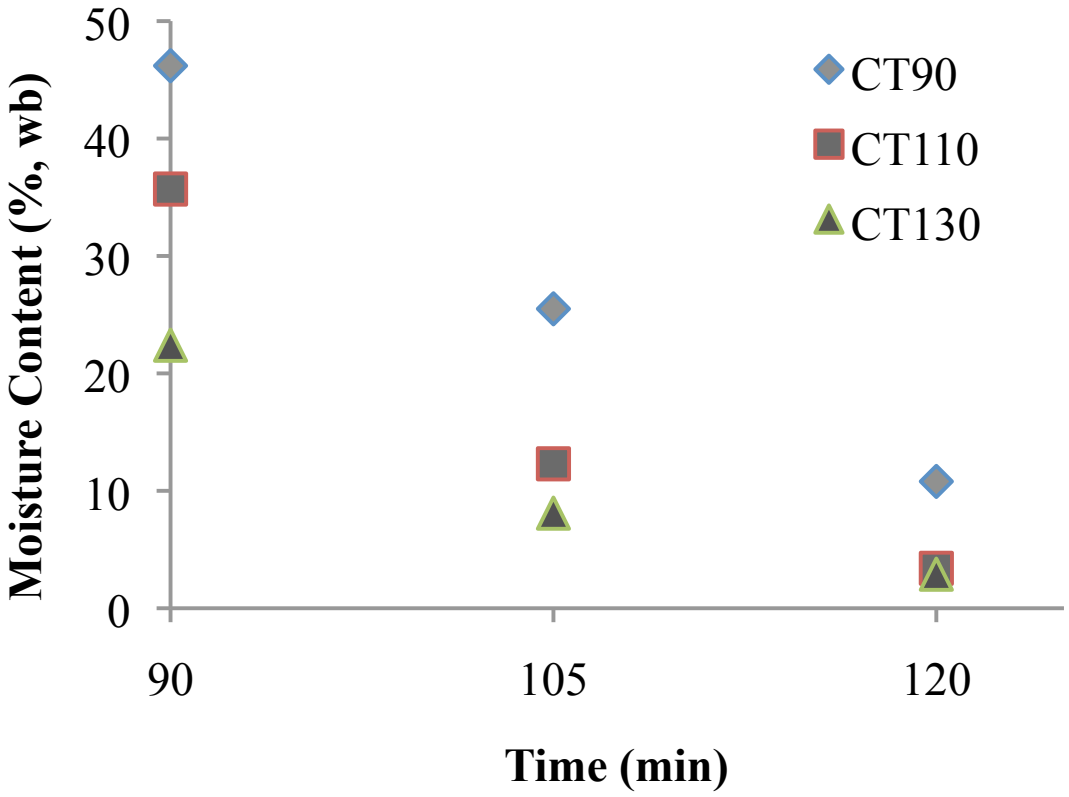


Figure 2.5 MC of vacuum belt dried blueberries as a function of time showing varying drying rates for each conduction temperature.

CHAPTER 3

VACUUM BELT DRYING OF RABBITEYE BLUEBERRIES: INFLUENCE OF DRYING CONDITIONS ON MOISTURE PROPERTIES AND ANTIOXIDANT CAPACITY[1]

[1] PALLAS, LAURA A., BILLARD, LYNNE, PEGG, RONALD B., and KERR, WILLIAM L. To be submitted to *Journal of Food Engineering*.

Abstract

Rabbiteye blueberries (*Vaccinium ashei* 'Tifblue') were vacuum belt dried based on a split-split plot experimental design with three conduction temperatures from 90 to 130 °C, two radiation temperatures from 100 to 120 °C, two drying times from 90 to 105 min, with and without mechanical skin abrasion, and two size categories. Freezing prior to drying markedly ($p<0.05$) reduced the drying time, whereas size and mechanical abrasion did not. A smaller split plot experimental design with three conduction temperatures (90 to 130 °C) and three drying times (90 to 120 min) was used to determine drying effects on total monomeric anthocyanins (TMA), total phenolics content (TPC), and hydrophilic-oxygen radical absorbance capacity ($H\text{-}ORAC_{FL}$). TPC values were not impacted by vacuum belt drying while higher conduction temperatures (130 °C) reduced TMA values. $H\text{-}ORAC_{FL}$ values maintained or increased at all drying times from 90 to 120 min with the conduction temperature at 110 °C compared to control values. Continuous vacuum belt drying offers an uninterrupted method of drying blueberries in less time than hot air drying without detriment to the antioxidant activity of the dried product.

3.1 Introduction

Blueberries are an important commercial fruit, and are a good source of vitamin C, manganese and antioxidants, including the anthocyanins that give them color. In the United States, 349 million pounds of blueberries were produced in 2008 with 56 % sold as fresh fruit (USDA, 2011). Of these, 44 % were further-processed by drying or freezing. As production of blueberries continues to increase, effective drying offers many benefits including increased off-season availability, increased consumption convenience, reduced costs compared to frozen storage, and the capability to be used in many value-added products.

Commercially dried blueberries often contain added sugar from initial steps that osmotically dehydrate the fruit and add solids. In addition, berries may be scarified to enhance transfer of moisture through the cuticle layer. Partially dried and sugar infused berries are then dried with hot air to 12-18 % moisture. With increasing focus on the health benefits afforded by blueberries, several studies have explored the stability of antioxidant constituents in non-infused and sugar-infused blueberries after hot air drying (Grabowski et al., 2007; Lohachoompol et al., 2004; Lohachoompol et al., 2007; Mejia-Meza et al., 2008; Stojanovic & Silva, 2007; Vaghri et al., 2000). Losses in total anthocyanins and phenolics can be greater than 50 %. Part of this may be due to thermal degradation, and part to leaching of compounds into the osmotic solutions (Sapers & Phillips, 1985). While lyophilization is widely accepted as the best drying method for retention of heat sensitive compounds in foods, batch processing, long drying times, and economic considerations limit the widespread use of freeze-drying commercially. Radiant

zone drying has shown some promise for limiting changes in antioxidant capacity during drying of blueberry extracts and purees (Chakraborty et al., 2009).

Vacuum drying is receiving increased attention for drying sensitive products more quickly than lyophilization, and with a greater retention of heat sensitive compounds than by hot air drying. Due to very low pressures, fast drying can occur without the product temperature reaching high values. A particular variant is the continuous vacuum belt dryer, in which a sample is introduced without breaking the vacuum, and is conveyed along a heated belt and collected in a hopper. Thus, vacuum belt drying (VBD) has the potential for continuously dehydrating fruits and vegetables. Clydesdale (1984) studied VBD and hot air drying of Japanese yams, and related the VBD rates to temperature and vacuum. Wang et al. (2007) showed that VBD of banana puree yielded better retention of initial volatiles than hot air dried puree. Liu et al. (2009) employed a vacuum belt dryer to dehydrate *Panax notoginseng* extract, studying the effects of vacuum, temperature, feed rate, and drying time. Another unique feature is that product on the belt can be passed over several conduction heating zones with different set temperatures. Thus, many factors influence the drying rate in a vacuum belt dryer and include operating pressure, cascading temperature profiles, belt speed, and the presence of secondary radiation heaters. Only a few research studies have been published on VBD, and this has limited its use in commercial operations.

The main objective of the present study was to better understand the impact of blueberry size, physical pretreatment (skin abrasion), conduction temperature, radiation temperature, drying time, and their interactions on the moisture content (MC) and water activity (a_w) of vacuum belt dried blueberries, starting with either refrigerated or frozen

berries. This was implemented using a split-split plot study, which allows a form of restricted randomization when some variables are harder to change than others. The second objective was to determine the impact of drying conditions on antioxidant constituents of cultivated blueberries by measuring changes in total anthocyanins content, total phenolics content, and oxygen radical scavenging capacity. The latter studies were done using a smaller split plot design to concentrate on those samples that would be suitable as dried fruit in commercial applications.

3.2 Materials & Methods

3.2.1 Sizing and Pretreatment

Ripe rabbiteye blueberries (*Vaccinium ashei* 'Tifblue' and 'Brightwell') were machine-harvested in Alma, GA. 'Tifblue' blueberries were commercially individually quick frozen (IQF) and stored at -20 °C up to three months prior to drying while 'Brightwell' blueberries were refrigerated at 4 °C no more than 21 days after harvesting. Blueberries were separated into small and large size categories using a steel plate screen with 12.7 mm diameter perforations. "Small" blueberries included those with 12.7 mm or smaller diameter, while "large" blueberries were those with a diameter greater than 12.7 mm.

Before drying, berries were promptly removed from refrigeration or the freezer. Half of each blueberry size group was subjected to mechanical abrasion as described by Lohachoompol (2007). Briefly, ~50g of berries were placed in a PVC cylinder 19 cm long and 8.9 cm wide, in which 100 grit sand paper had been glued to the inner walls. After closing the cylinder with end caps, the cylinder was placed on a lathe and rotated at 100 rpm for 2 min. This resulted in visible removal of the waxy outer layer of the berries

with minimal pigment bleeding. Abraded and non-abraded berries were immediately returned to refrigerated or freezing conditions until drying. There was no more than 20 min between abrasion and loading into the dryer. Non-abraded blueberries were subjected to the same temperature changes as abraded samples to minimize variation introduced by temperature differences.

3.2.2 Drying

Blueberries were dried in a 0.2 m^2 area laboratory-scale vacuum belt dryer (Model: Zwag LKM-101, Zschokke Wartmann, Ltd., Bucher, Döttingen, Switzerland), which included a 20.3 cm wide Teflon belt riding over three conduction heaters. A radiation plate 22.9 cm wide was adjusted to a height of 4.7 cm above the conduction plates. Drying temperature and time conditions included top plate radiation temperatures (100 or 120 °C), bottom plate conduction temperatures (90, 110, or 130 °C), and drying durations (90, 105, or 120 min). For each drying run, three batches of 50 g refrigerated or frozen blueberries were placed onto the belt with each batch aligned directly on top of one conduction plate such that one radiation and one drying time corresponded to a drying run. Treatment combinations were randomly determined for radiation temperature (RT), conduction plate temperature (CT), drying time (DT), blueberry size (small or large), and blueberry pre-abrasion (Ab). The vacuum (< 3.6 kPa) was pulled using a DVT AquaSeal 80 CFM vacuum pump (Michigan City, IN). Samples designated for antioxidant measurements were placed into 150 mL Whirl-Pak® bags (Fisher Scientific Ltd., Suwanee, GA) and stored at -80 °C prior to analysis.

3.2.3 Moisture Content and Water Activity

The MC of fresh and dried blueberries was determined according to AOAC Method 934.06 (AOAC, 1995) with modifications. Five blueberries were cut in half using a razor blade and weighed in pre-dried aluminum weighing dishes (Fisher Scientific). Samples were dried in a Model 1430MS vacuum oven (VWR International, West Chester, PA) at 70 °C and 40 kPa for 24 h, or until a constant mass was achieved. The MC was determined in triplicate per drying batch. For a_w, three to five blueberries were cut in half and placed in a sample cup. The a_w was determined using an AquaLab Model CX-2 (Decagon Devices Inc, Pullman, WA) at 25 ± 3 °C; a_w measurements were performed in triplicate per drying batch.

3.2.4 Extraction of Polyphenolics

Chemical analyses were performed on a reduced number of samples: a smaller split plot design was used which incorporated one size (large), non-abraded, and one radiation temperature (100 °C) based on drying results of the larger frozen blueberry factorial design. Thus, extracts were compiled over three conduction temperatures (90, 110, and 130 °C) and three drying times (90, 105, and 120 min). In addition, due to limited availability of fresh blueberries, only frozen blueberries were used for phytochemical analysis.

Both non-dried and dried samples (stored at -80 °C) were lyophilized in a Freezemobile 25 SL Unitop 600L (Virtis Company, Gardiner, NY) at less than 26 Pa. The samples were placed on the heating plates at -45 °C, and vacuum was applied once the internal blueberry temperature reached -40 °C. The plate temperature was increased to 30 °C once the chamber pressure was <7 kPa. Blueberries were dried until the internal

berry temperature reached 27 °C. All samples were lyophilized prior to extraction of polyphenolics to eliminate differences in MC between samples and thus variation in the extraction process.

Dried blueberries were ground in a coffee mill (Kitchen Aid, St. Joseph, MI). Blueberry powder and 80 % (v/v) aqueous acetone (1:10 w/v, respectively) were mixed in a 250 mL Erlenmeyer flask, which was loosely covered with aluminum foil and placed in an orbital shaker water bath (Model G76, New Brunswick Scientific, New Brunswick, NJ) at 45 °C for 30 min. After this period, the filtrate was passed through P8 filter paper (Fisher Scientific) into a second Erlenmeyer flask. The recovered sediment was then extracted twice more with 80 % (v/v) aqueous acetone as described above, each time pooling the filtrate. Acetone was removed from the filtrate using a R-210 Büchi Rotovapor (Büchi Corporation, New Castle, DE) at 40 °C; the evaporator was connected to a V-700 vacuum pump and V-850 controller (Büchi) set for 190 mbar. The aqueous residue was transferred to an aluminum dish, frozen and then lyophilized for 24 h to obtain a dry extract. Extracts were scraped and transferred to small vials and then sealed under a nitrogen headspace. Dry extracts were stored in a refrigerator until further analyzed.

3.2.5 Total Monomeric Anthocyanins (TMA)

The pH-differential method described by Giusti and Wrolstad (2001) was used to determine the TMA content in the dried blueberry preparations. Briefly, this method is based on a reversible color change of monomeric anthocyanin pigments with an alteration in the pH; that is, the colored oxonium-ion form exists at pH 1.0, and the colorless hemiketal form predominates at pH 4.5. The difference in absorbance of the pigments at

λ = 510 nm is proportional to the anthocyanin concentration; results were expressed as cyanidin-3-*O*-glucoside (C3G) equivalents, as C3G is a common anthocyanin in berries. Two buffer systems were employed in the assay: a 0.025 M potassium chloride buffer, pH 1.0, and a 0.4 M sodium acetate buffer, pH 4.5. Dried blueberry samples were dissolved in pH 1.0 and pH 4.5 buffers from an original concentration of ~1 mg/mL with a dilution factor of 7. After an incubation period of 15 min at room temperature to allow for optimal color development, absorbance readings were taken at λ = 510 and 700 nm with a 8453 UV-visible spectrophotometer (Agilent Technologies, Wilmington, DE). The pH differential absorbance was determined as follows:

$$Abs = (A_{510nm} - A_{700nm})_{@\ pH\ 1.0} - (A_{510nm} - A_{700nm})_{@\ pH\ 4.5} \quad (1)$$

The TMA content was calculated using the following equation:

$$TMA(mg\ C3G\ eq\ /\ L) = \frac{Abs \times MW \times DF \times 1000}{\varepsilon \times \ell} \quad (2)$$

where A = absorbance; MW = molecular weight (449.2 g/mol); DF = dilution factor; and ε = molar extinction coefficient (25,740 L cm^{-1} mol^{-1}). For easier comparison to literature values, the TMA content was calculated as mg C3G equivalents per g of extract, per 100 g of fresh weight (FW), and per g of dry matter (DM).

3.2.6 Total Phenolics Content (TPC)

The TPC of extracts was determined using Folin-Ciocalteu's phenol reagent as described by Singleton et al. (1999), with modifications for a FLUOstar Omega

microplate reader (BMG Labtech, Raleigh, NC). Gallic acid was employed as the standard. After the colorimetric reaction and a 60 min holding period, sample absorbance was measured at 750 nm in a flat-bottomed, clear polystyrene, 96-well plate (Fisher Scientific) in the FLUOstar Omega microplate reader, with path length correction selected prior to running the program. Each sample absorbance was measured in duplicate and averaged, and each extract was measured in triplicate. Results were calculated and reported as mg of gallic acid equivalents (GAE) per g of extract, per 100 g of FW, and per g DM.

3.2.7 Hydrophilic-Oxygen Radical Absorbance Capacity$_{FL}$ (H-ORAC$_{FL}$)

H-ORAC$_{FL}$ of blueberry extracts was determined as described by Prior et al. (2003) with modifications for a FLUOstar Omega microplate reader. Extracts were reconstituted with deionized water, vortexed until particles dispersed, and centrifuged (Centrific Model 228, Fisher Scientific) for 5 min to remove any particulate fines. The assay was carried out in a flat, clear-bottomed 96 well black plate (Costar #3631, Corning, Inc., Corning, NY). Except for the outside wells, each well received either 20 μL of diluted aqueous extract, 20 μL of Trolox (6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid) at concentrations of 6.25, 12.5, 25, 50, and 100 μM, or 40 μL of 75 mM phosphate buffer (pH 7.4) as the blank solution. The microplate reader was programmed to add 400 μL of fluorescein (0.11 μM), followed by 150 μL of 2,2′-azobis(2-amidinopropane) dihydrochloride (AAPH) (31.6 mM, Sigma-Aldrich Chemical Co., St. Louis, MO) to each well. All solutions had been previously incubated at 37 °C. The excitation wavelength was set at 485 nm. Emission was recorded at 520 nm after the addition of fluorescein and AAPH and every 192 s thereafter, until a 95 % loss of the

fluorescence was noted (~ 3 h). Results were calculated based on the fluorescein decay by calculating areas under the curves (AUC) for the phosphate buffer blanks, aqueous blueberry extract samples, and Trolox standards. A standard curve was obtained by plotting the known concentrations of Trolox against the respective AUC for each standard concentration. Final H-ORAC$_{FL}$ values were calculated using the regression equation of the standard curve expressed as μmol Trolox equivalents (TE) per g of extract, per 100 g of FW, and per g DM.

3.2.8 Statistical Analysis

A randomized split-split plot design was used to examine multiple factors (DT, CT, RT, size, and Ab), with each response analyzed individually (Table 3.1). MC and a_w contained two blocks: drying time and radiation temperature. In the split-split plot design, three stages of randomization occurred. In the first stage, the levels of time were randomized to the whole plots within each block; in the second, the RT levels were randomized to the split-plots within each whole plot of every block; and in the third randomization stage, the rest of the factors (size, CT, and Ab) were randomized within the split-split plots such that one drying run corresponded to one drying time, one RT, and three random combinations of size, Ab, and CT. Three replications were performed for each combination. SAS 9.1 was used to analyze the split-split plot randomized drying design, split by RT and drying time. The antioxidant analysis was analyzed using a split plot randomized design, split by only drying time (Table 3.1).

3.3 Results & Discussion

In general, vacuum belt dried blueberries retained their original size and had a dry, porous texture similar to freeze-dried blueberries, but with substantially less drying

time (1-2 h as compared to 12-24 h). The blueberries did not shrivel as is typical with hot air drying. However, frozen blueberries subject to VBD for 120 min showed considerable deterioration of quality, as noted by substantial browning and a burnt flavor, particularly for higher CT and RT and small blueberries. Due to unacceptable blueberry quality, the split-split plot design was reduced to two drying times (90 min and 105 min). Nevertheless, samples from the longer drying time were retained for antioxidant analysis.

3.3.1 Moisture Properties

Table 3.2 shows the MC and a_w of both refrigerated and frozen blueberries subjected to continuous VBD. For refrigerated berries, the MC varied from 4.3 to 46.2 %, with corresponding a_w values of 0.361 to 0.883. For frozen berries, the final MC of the dried blueberries varied from 2.2 to 24.6 % with corresponding a_w values of 0.246 to 0.667. Clearly, frozen blueberries dried under the same conditions possessed lower MC and a_w values than the fresh refrigerated blueberries. In general, the frozen blueberries could be dried to ~20 °C less for the same amount of time (90 min or 105 min) to achieve similar MC and a_w values as vacuum belt dried refrigerated blueberries. For instance, frozen blueberries dried for 90 min at 90 °C had similar MC and a_w values to unfrozen blueberries dried for 90 min at 110 °C. Similarly, the MC and a_w values of the frozen blueberries dried for 90 min at 110 °C were analogous to those for refrigerated blueberries dried for 90 min at 130 °C.

Several factors may contribute to different drying times for frozen blueberries compared to refrigerated blueberries. First, the thermal conductivity of ice is roughly four times greater than that of water, encouraging more rapid heat transfer from the conduction plates. Heat transfer also occurs more quickly in the frozen blueberry due to a

larger temperature difference between the blueberry and the conduction plate. For refrigerated blueberries, much of the initial water was removed near 28 °C. For frozen berries, the product temperature remained much lower. Of course the greater the heat that needs to be removed from frozen berries acts counter to any advantages to improved heat transfer. One significant reason that frozen blueberries may dry faster is that damage occurs to the parenchyma cells, along with creation of crevices in the waxy cuticle layer, as ice develops during the freezing process (Lohachoompol, 2007). During drying, water can more rapidly diffuse through the porous spaces that are created. MacGregor (2005) suggested that the numerous cracks in the skin of IQF blueberries diminished the resistance to moisture transfer during the initial stages of drying.

Several factors determined the final MC and a_w of frozen vacuum belt dried blueberries (Table 3.3). As expected, increased drying time and conduction temperature decreased the final MC and a_w of the dried blueberries. Interaction between CT and time was significant for both MC and a_w, and a linear model described the dependence on CT. The interaction between drying time and CT indicates that the linear fit for CT had a different slope for different drying times.

Blueberry size alone did not impact the final MC or a_w. However, there was an interaction between size and CT. For instance, at CT = 90 °C, the average a_w for small blueberries (0.557) was similar to that of large blueberries (0.556). At CT = 110 °C, the larger blueberries exhibited a lower a_w (0.306) than small blueberries (0.394). At CT = 130 °C, however, larger blueberries had a higher a_w (0.283) than small blueberries (0.241). In contrast, size was a significant factor for vacuum belt dried blueberries from unfrozen berries.

Abrasion was significant in several interaction effects such as Ab*RT*DT, Ab*CT*DT, Ab*CT*RT*DT, and Ab*Size*DT. The pretreatment of abrasion had no effect on frozen blueberries dried 90 min for each CT (90, 110, and 130 °C). The difference with skin abrasion was more evident at 105 min. Non-abraded blueberries dried for 105 min at CT = 90°C had a higher a_w (0.509) than abraded blueberries (0.382) under the same conditions. At higher CT values (110 and 130 °C), non-abraded blueberries dried for 105 min had lower a_w (0.247 at 110 °C; 0.224 at 130 °C) than abraded blueberries (0.359 at 110 °C; 0.268 at 130 °C). This is contrary to other published results, in which mechanical skin abrasion has been shown to reduce the drying time of blueberries and plums (Di Matteo et al., 2002; Lohachoompol et al., 2007). In those studies, the fruits were not frozen prior to drying. It is possible that a longer abrasion time may be required to adequately disrupt the frozen cuticle layer. Alternatively, because freezing causes disruptions of cells both on the surface and within the blueberry, this in itself may improve moisture diffusion throughout the drying process; thus, no further benefit is to be gained by abrasion.

It is worth noting that most of the berries were dried to fairly low a_w, certainly below levels of 0.5 to 0.65 that might be found for conventional dried blueberries meant for direct consumption. Thus, many of the vacuum belt dried samples would be more appropriate for the production of powders, or for use in dry products where the berries are destined for rehydration.

3.3.2 Antioxidant Capacity

As RT, size, and abrasion were not significant factors for frozen blueberries, the measurements of antioxidant capacity were studied using a reduced split plot design. All

dried blueberry samples chosen from the larger split-split plot study for antioxidant measurement were reduced to one RT (100 °C), blueberry size (large), and pretreatment (non-abraded), leaving CT and drying time as variables. As previously mentioned, drying times of 120 min resulted in unacceptable quality. Nevertheless, the data were considered important for understanding the impact of drying conditions on antioxidant constituents in blueberries.

3.3.2.1 Total Monomeric Anthocyanin (TMA) Content

Table 3.4 shows the TMA, TPC and H-ORAC$_{FL}$ values for blueberries subjected to different drying times and conduction temperatures. ANOVA results are summarized in Table 3.5. The TMA value for the frozen control (16.7 mg C3G eq./g extract = 190 mg C3G eq./100g FW) was somewhat lower than that reported by Moyer et al. (2002) for *Vaccinium ashei* Reade (242 mg C3G eq./100g FW), and higher than that reported by Prior et al. (1998) for late harvest *V. ashei* Reade 'Tifblue' (154 mg C3G eq./100g FW), by Stojanovic and Silva (2007) for culled *V. ashei* Reade (136 mg C3G eq./100g FW), and by Connor et al. (2002) for *V. corymbosum* (183 mg C3G eq./100g FW). Anthocyanin content is known to vary among blueberry cultivars, maturity at harvest, and year of harvest (Kalt & McDonald, 1996). For the vacuum belt dried blueberries, TMA values fell within the range of 8.2 to 22.8 mg C3G eq./g extract. Values for frozen untreated blueberries were comparable to the 11.9 mg C3G eq./g DM reported by Lohachoompol (2007).

Conduction temperature was found to be a significant factor, and higher temperatures reduced the anthocyanin content (Table 3.5). Other studies have demonstrated the sensitivity of anthocyanins to heat damage (Lohachoompol et al., 2004;

Mejia-Meza et al., 2008; Skrede et al., 2000). Lohachoompol (2007) found that freeze-drying did not reduce total anthocyanins in *V. corymbosum* 'Crunchie', but resulted in a small decrease in *V. ashei* 'Powderblue' (11.86 to 9.30 mg C3G eq./g DW). Radiant zone drying has also been shown to have little effect on the anthocyanin content of dried blueberry products (Chakraborty et al., 2009), at least those made from extracts or purees. In contrast, changes in anthocyanins were much more pronounced with cabinet-dried and heat-pump dried blueberries at air temperatures between 40 and 90 °C for both rabbiteye and highbush blueberries (Lohachoompol, 2007). Specifically, TMA values of fresh rabbiteye (13.7 C3G eq./g DW) were reduced to 4.5 and 0.79 mg C3G eq./g DW with multistage cabinet drying, temperature cascading from 90 to 50 °C, and heat pump drying at 40 °C, respectively. Changes in the anthocyanins depended not only on temperature, but also pretreatments such as abrasion and the type and concentration of osmotic drying agents.

In most reported cases of hot air drying of blueberries, the target product a_w is typically between 0.60 and 0.65, in order to produce shelf-stable intermediate moisture fruits. In this study, the final product a_w varied between 0.246 and 0.667. Thus, some of the results reported here are from more extensively dried product. It also is worth noting that the vacuum belt dried blueberries were dried under vacuum; therefore, any changes in TMA were not mediated by oxygen.

The anthocyanin content of vacuum belt dried blueberries also varied with drying time (Table 3.5). This most likely was influenced by lower TMA levels for the 105 min-130 °C combination, and greater TMA levels for the 90 min-90 °C and 120 min-110 °C combinations. In some cases, TMA levels were higher than that of the control. This may

be due to better extraction efficiency for the dried product related to degradation of the epidermal layer. Scibisz and Mitek (2007) reported higher anthocyanin contents in frozen blueberries than fresh blueberries due to easier extraction as a result of cell wall rupture caused by freezing. Vacuum belt dried samples dried for 105 min and 130 °C exhibited a 52 % loss in anthocyanin content, and a final MC of 2.2 %. Samples dried to a_w values < 0.3 were most subject to high product temperature. In other words, during initial drying, the product temperature stayed below 40 °C until a_w values of ~0.8 were reached. As drying proceeded, temperatures gradually increased toward the plate temperature.

3.3.2.2 Total Phenolics Content (TPC)

TPC values of vacuum belt dried blueberries varied from 40.9 to 47.4 mg GAE/g extract (Table 3.4). The TPC values of frozen untreated blueberries in this study (41.8 mg GAE/g = 527 mg GAE/100g FW) were comparable to previously reported TPC values for fresh blueberries: 550 mg GAE/100g FW for culled *V. ashei* Reade (Stojanovic & Silva, 2007); 717 mg GAE/100g FW for *V. ashei* Reade (Moyer et al., 2002); 409 mg GAE/100g FW for *V. ashei* 'Tifblue' late harvest (Prior et al., 1998); 428 mg GAE/100g FW for *V. corymbosum* L. (Scibisz & Mitek, 2007); 493 mg CAE/100g FW for *V. corymbosum* L. (Connor et al., 2002); and 425 to 679 mg GAE/100g FW for *V. corymbosum* L. (Vaghri et al., 2000). Experimental variations, along with differences in blueberry cultivar, harvest year, location, and climatic conditions, contribute to the variations in reported values of phenolics content (Connor et al., 2002; Prior et al., 1998).

Overall, there were no significant differences between the frozen control blueberries and VBD treatments when compared pair-wise (Table 3.4). Nevertheless, regression analysis showed that drying time was a significant factor (Table 3.5). This

seems to have been influenced by relatively higher values at 90 min-130 °C and 120 min-110 °C (47.4 and 44.9 mg GAE/g). In any event, there is no indication that much thermal degradation of phenolic compounds occurred for vacuum belt dried blueberries dried for 90 to 120 min at temperatures between 90 and 130 °C.

Working with a unique radiant zone drying system, Chakraborty et al. (2009) found no difference in TPCs of blueberry extract, juice, or puree. Bohm et al. (2006) reported no differences between the TPC values of lyophilized and unprocessed strawberries, while hot air drying at 60 °C and microwave vacuum drying both reduced the TPC of strawberries. Larrauri et al. (1997) showed that hot air drying at higher temperatures (100 and 140 °C) reduced the phenolics content of red grape pomace more than freeze-drying and hot air drying at a lower temperature of 60 °C. Freeze-dried Saskatoon berries retained 60-90 % of the TPCs measured in fresh-frozen berries (depending on variety), while vacuum-microwave dried berries retained 48-64 % of TPCs and hot air dried berries retained 34-43 % of TPCs (Kwok et al., 2004). Microwave-assisted vacuum drying yielded dried blueberries with higher TPC (297 mg/100g) compared to those prepared by hot air drying (37.7 mg EA/100g) (Mejia-Meza et al., 2008).

3.3.2.3 Hydrophilic-Oxygen Radical Absorbance Capacity$_{FL}$ (H-ORAC$_{FL}$)

H-ORAC$_{FL}$ values of the fresh blueberries in this study (481μmol TE/g extract = 5870 μmol TE/100g FW and 356 μmol TE/g DM) were greater than the 3780 μmol TE/100g FW reported for late-harvested ‘Tifblue’ (Prior et al., 1998), the 175 μmol TE/g DM for ‘Tifblue’ (Prior et al., 2001), and the 91-156 μmol TE/g DM for *V. ashei* (Lohachoompol, 2007). However, the values reported in this study were less than the

11,100 to 13,100 μmol TE/100g FW found for *V. ashei* Reade (Moyer et al., 2002). Caution must be exercised when comparing H-ORAC$_{FL}$ data across laboratories as analytical techniques and bases in which data are reported are not always similar.

Overall, H-ORAC$_{FL}$ values for vacuum belt dried blueberries ranged from 437 to 682 μmol TE/g extract (Table 3.4). The H-ORAC$_{FL}$ values varied both with drying temperature and the interaction time*CT (Table 3.5). That is, blueberries dried for 90 min at 110 °C or 130 °C had significantly higher H-ORAC$_{FL}$ values compared to control blueberries, as did blueberries dried 120 min at 110 °C. Other H-ORAC$_{FL}$ values did not vary significantly with those for the frozen control blueberries. These results are in keeping with other investigations as drying has been reported to have varying effects on antioxidant activity. Several studies have reported that freeze-dried blueberries retain the highest antioxidant activity followed by VMD and lastly hot air drying (Bohm et al., 2006; Kwok et al., 2004; Mejia-Meza et al., 2008; Stojanovic & Silva, 2007; Vaghri et al., 2000). In any event, vacuum belt dried blueberries had H-ORAC$_{FL}$ values similar to that of the control, and in some cases slightly higher ones.

3.4 Conclusions

Continuous vacuum belt drying shows promise as an alternative to hot air and freeze-drying for rapid drying of frozen blueberries to a_w <0.5 in less than 1 to 2 h. Freezing prior to drying reduced the drying time while smaller blueberries and mechanical abrasion did not reduce drying times for frozen berries. The anthocyanin content, total phenolics content, and oxygen radical absorbance capacity were not greatly affected except at very low a_w (< 0.250) and MC (< 3 %) thereby suggesting that vacuum belt drying does not greatly impact the integrity of antioxidants during the drying process.

References

Bohm, V., Kuhnert, S., Rohm, H. & Scholze, G., (2006). Improving the nutritional quality of microwave-vacuum dried strawberries: A preliminary study. *Food Science and Technology International* 12(1), 67-75.

Chakraborty, M., Savarese, M., Harbertson, E., Harbertson, J. & Ringer, K.L., (2009). Effect of the novel radiant zone drying method on anthocyanins and phenolics of three blueberry liquids. *Journal of Agricultural and Food Chemistry* 58(1), 324-330.

Clydesdale, F.M., (1984). Color measurement, in: Gruenwedel, D.W. & Whitaker, J. (Eds.), *Food Analysis: Principles and Techniques. Vol. 1. Physical Characteristics*. Marcel Dekker, New York.

Connor, A.M., Luby, J.J., Tong, C.B.S., Finn, C.E. & Hancock, J.F., (2002). Genotypic and environmental variation in antioxidant activity, total phenolic content, and anthocyanin content among blueberry cultivars. *J. Amer. Soc. Hort. Sci.* 127(1), 89-97.

Di Matteo, M., Cinquanta, L., Galiero, G. & Crescitelli, S., (2002). Physical pre-treatment of plums (*Prunus domestica*). Part 1. Modelling the kinetics of drying. *Food Chemistry* 79(2), 227-232.

Giusti, M.M. & Wrolstad, R.E., (2001). Characterization and measurement of anthocyanins by spectroscopy. Unit F1.2, in: Wrolstad, R.E. (Ed.), *Current Protocols in Food Analytical Chemistry*. John Wiley & Sons, Inc., New York, pp. F1.2.1-F1.2.13.

Grabowski, S., Marcotte, M., Quan, D., Taherian, A.R., Zareifard, M.R., Poirier, M. & Kudra, T., (2007). Kinetics and quality aspects of Canadian blueberries and cranberries dried by osmo-connective method. *Drying Technology* 25(2), 367-374.

Kalt, W. & McDonald, J.E., (1996). Chemical composition of lowbush blueberry cultivars. *Journal of the American Society for Horticultural Science* 121(1), 142-146.

Kwok, B.H.L., Hu, C., Durance, T. & Kitts, D.D., (2004). Dehydration techniques affect phytochemical contents and free radical scavenging activities of Saskatoon berries (*Amelanchier alnifolia* Nutt.). *Journal of Food Science* 69(3), 122-126.

Larrauri, J.A., Ruperez, P. & Saura-Calixto, F., (1997). Effect of drying temperature on the stability of polyphenols and antioxidant activity of red grape pomace peels. *Journal of Agricultural and Food Chemistry* 45(4), 1390-1393.

Liu, X., Qiu, Z., Wang, L., Cheng, Y., Qu, H. & Chen, Y., (2009). Mathematical modeling for thin layer vacuum belt drying of *Panax notoginseng* extract. *Energy Conversion and Management* 50(4), 928-932.

Lohachoompol, V., (2007). Effects of drying on anthocyanins in blueberries. *Food Science and Technology, School of Chemical Sciences and Engineering*. The University of New South Wales, Sydney, Australia.

Lohachoompol, V., Srzednicki, G. & Craske, J., (2004). The change of total anthocyanins in blueberries and their antioxidant effect after drying and freezing. *Journal of Biomedicine and Biotechnology* 2004(5), 248-252.

Lohachoompol, V., Srzednicki, G. & Mulholland, M., (2007). Effects of pre-treatments on drying kinetics and anthocyanin content in dried blueberries, in: Chen, G. (Ed.), *5th Asia-Pacific Drying Conference*, Hong Kong, pp. 1077-1084.

MacGregor, W., (2005). Effects of air velocity, air temperature, and berry diameter on wild blueberry drying. *Drying Technology* 23(1-2), 387-396.

Mejia-Meza, E.I., Yanez, J.A., Davies, N.M., Rasco, B., Younce, F., Remsberg, C.M. & Clary, C., (2008). *Improving nutritional value of dried blueberries (Vaccinium corymbosum L.) combining microwave-vacuum, hot-air drying and freeze drying technologies*. Journal 4(5), article 5. Online: http://www.bepress.com/ijfe/vol4/iss5/art5/

Moyer, R.A., Hummer, K.E., Finn, C.E., Frei, B. & Wrolstad, R.E., (2002). Anthocyanins, phenolics, and antioxidant capacity in diverse small fruits: *Vaccinium*, *Rubus*, and *Ribes*. *Journal of Agricultural and Food Chemistry* 50(3), 519-525.

Prior, R.L., Cao, G.H., Martin, A., Sofic, E., McEwen, J., O'Brien, C., Lischner, N., Ehlenfeldt, M., Kalt, W., Krewer, G. & Mainland, C.M., (1998). Antioxidant capacity as influenced by total phenolic and anthocyanin content, maturity, and variety of Vaccinium species. *Journal of Agricultural and Food Chemistry* 46(7), 2686-2693.

Prior, R.L., Hoang, H., Gu, L.W., Wu, X.L., Bacchiocca, M., Howard, L., Hampsch-Woodill, M., Huang, D.J., Ou, B.X. & Jacob, R., (2003). Assays for hydrophilic and lipophilic antioxidant capacity (oxygen radical absorbance capacity (ORAC(FL))) of plasma and other biological and food samples. *Journal of Agricultural and Food Chemistry* 51(11), 3273-3279.

Prior, R.L., Lazarus, S.A., Cao, G., Muccitelli, H. & Hammerstone, J.F., (2001). Identification of procyanidins and anthocyanins in blueberries and cranberries (Vaccinium spp.) using high-performance liquid chromatography/mass spectrometry. *Journal of Agricultural and Food Chemistry* 49(3), 1270-1276.

Sapers, G.M. & Phillips, J.G., (1985). Leakage of anthocyanins from skin of raw and cooked highbush blueberries (*Vaccinium corymbosum* L.). *Journal of Food Science* 50, 437-439, 443.

Scibisz, I. & Mitek, M., (2007). The changes of antioxidant properties in highbush blueberries (*Vaccinium corymbosum* L.) during freezing and long-term frozen storage. *Acta Scientiarum Polonorum - Technologia Alimentaria* 6(4), 75-81.

Singleton, V.L., Orthofer, R. & Lamuela-Raventos, R.M., (1999). Analysis of total phenols and other oxidation substrates and antioxidants by means of Folin-Ciocalteu reagent. *Methods in Enzymology* 299, 152-178.

Skrede, G., Wrolstad, R.E. & Durst, R.W., (2000). Changes in anthocyanins and polyphenolics during juice processing of highbush blueberries (*Vaccinium corymbosum* L.). *Journal of Food Science* 65(2), 357-364.

Stojanovic, J. & Silva, J.L., (2007). Influence of osmotic concentration, continuous high frequency ultrasound and dehydration on antioxidants, colour and chemical properties of rabbiteye blueberries. *Food Chemistry* 101(3), 898-906.

USDA, (2011). Noncitrus fruits and nuts: 2010 summary. *National Agricultural Statistics Service*.

Vaghri, Z., Scaman, C.H., Kitts, D.D., Durance, T. & McArthur, D.A., (2000). Quality of the vacuum microwave dried blueberries in terms of color, composition, and antioxidant activity, *12th International Drying Symposium*, paper 318 ed. Elsevier Science, Amsterdam, pp. 1-10.

Wang, J., Li, Y.Z., Chen, R.R., Bao, J.Y. & Yang, G.M., (2007). Comparison of volatiles of banana powder dehydrated by vacuum belt drying, freeze-drying and air-drying. *Food Chemistry* 104(4), 1516-1521.

Tables

Table 3.1 Treatment combinations for the (a) split-split plot study on moisture content and water activity and the (b) split-plot study on antioxidant activity (TMA, TPC, and H-ORAC$_{FL}$).

(a) Split-split plot variables and levels for moisture properties

Variable and Units		Levels		
DT	Drying time (mins)	90	105	120
CT	Conduction temperature (°C)	90	110	130
RT	Radiation temperature (°C)	100	120	
Size	Blueberry size	Large	Small	
Ab	Skin abrasion	None	Abraded	

(b) Split plot variables and levels for antioxidants

Variable and Units		Levels		
DT	Drying time (mins)	90	105	
CT	Conduction temperature (°C)	90	110	130
RT	Radiation temperature (°C)	100		
Size	Blueberry size	Large		
Ab	Skin abrasion	None		

Table 3.2 Moisture content (g H_2O/100g) and water activity (a_w) values for vacuum belt dried blueberries using fresh (refrigerated) or frozen blueberries.

Drying Time (min)	CT (°C)	Moisture Content		Water Activity	
		Refrigerated	Frozen	Refrigerated	Frozen
90	90	46.2 ± 13.0	24.6 ± 15.6	0.883 ± 0.075	0.667 ± 0.184
90	110	25.4 ± 15.4	9.2 ± 10.3	0.693 ± 0.193	0.397 ± 0.203
90	130	11.0 ± 11.5	3.2 ± 5.2	0.493 ± 0.195	0.278 ± 0.131
105	90	35.7 ± 14.8	13.4 ± 15.9	0.810 ± 0.124	0.446 ± 0.224
105	110	11.8 ± 11.8	5.3 ± 8.1	0.496 ± 0.198	0.303 ± 0.182
105	130	3.4 ± 5.6	2.2 ± 3.2	0.358 ± 0.110	0.246 ± 0.084
120	90	20.7 ± 18.5		0.602 ± 0.240	
120	110	7.8 ± 9.2		0.418 ± 0.160	
120	130	4.3 ± 10.3		0.361 ± 0.149	

Table 3.3 ANOVA table for moisture content and water activity of frozen vacuum belt dried blueberries.

Source	df	Moisture Content p value	Water Activity p value
Whole Plot			
Time (DT)	1	0.001	0.0004
Rep	5	0.010	0.008
Error Whole Plot	5		
Split Plots			
RT	1	0.961	0.149
DT*RT	1	0.685	0.829
Error Split Plots	10		
Split-Split Plots			
CT	2	<0.0001	<0.0001
Linear CT	1	<0.0001	<0.0001
CT*DT	2	0.002	0.0002
DT*LinearCT	1	0.001	<0.0001
CT*RT	2	0.0001	0.0001
CT*RT*DT	1	0.245	0.033
Size	1	0.352	0.406
Size*CT	2	0.033	0.015
Size*QuadraticCT	1	0.017	0.006
Abrasion (Ab)	1	0.182	0.337
Ab*RT*DT	1	0.030	0.135
Ab*CT*DT	2	0.025	0.008
Ab*CT*RT*DT	2	0.018	0.051
Ab*Size*DT	1	0.013	0.052
Error Split-Split Plots	220		
Total	287		

Table 3.4 Antioxidant measurements for vacuum belt dried blueberries (TMA-total monomeric anthocyanins, TPC-total phenolics content, H-ORAC$_{FL}$-hydrophilic-oxygen radical absorbance capacity).

DT (min)	CT (°C)	TMA mg C3G eq. / g extract	TMA mg C3G eq. / 100g FW	TMA mg C3G eq. / g DM	TPC mg GAE / g extract	TPC mg GAE / 100g FW	TPC mg GAE / g DM	H-ORAC$_{FL}$ µmol TE / g extract	H-ORAC$_{FL}$ µmol TE / 100g FW	H-ORAC$_{FL}$ µmol TE / g DM
Control		16.7 ± 1.0	190 ± 11	11.5 ± 0.7	41.8 ± 3.7	527 ± 27	30.9 ± 2.8	481 ± 18	5870 ± 220	356 ± 13
90	90	20.1 ± 1.2	229 ± 13	13.9 ± 0.8	40.9 ± 4.5	499 ± 54	30.2 ± 3.3	583 ± 32	7120 ± 390	432 ± 23
90	110	18.4 ± 2.6	212 ± 28	12.8 ± 1.7	43.1 ± 9.2	527 ± 113	31.9 ± 6.8	609 ± 55	7440 ± 670	451 ± 41
90	130	14.4 ± 2.6	164 ± 30	9.9 ± 1.8	47.4 ± 8.2	578 ± 100	35.1 ± 6.1	609 ± 109	7440 ± 1300	451 ± 81
105	90	17.8 ± 1.8	201 ± 22	12.2 ± 1.3	41.7 ± 7.2	509 ± 88	30.8 ± 5.4	571 ± 98	6970 ± 1200	422 ± 73
105	110	16.0 ± 1.2	182 ± 14	11.1 ± 0.8	43.1 ± 6.5	526 ± 80	31.9 ± 4.8	577 ± 54	7040 ± 660	427 ± 40
105	130	8.2 ± 0.7	93 ± 8	5.7 ± 0.5	40.9 ± 4.7	499 ± 57	30.3 ± 3.5	496 ± 71	6050 ± 870	367 ± 53
120	90	17.9 ± 2.8	204 ± 32	12.4 ± 1.9	40.9 ± 6.4	499 ± 78	30.3 ± 4.7	437 ± 82	5340 ± 1000	324 ± 60
120	110	22.8 ± 0.3	259 ± 3	15.7 ± 0.2	44.9 ± 0.8	541 ± 10	32.8 ± 0.6	682 ± 76	8320 ± 920	504 ± 56
120	130	17.3 ± 0.4	197 ± 4	11.9 ± 0.3	41.9 ± 2.1	512 ± 25	31.0 ± 1.5	627 ± 66	7660 ± 810	464 ± 49

Table 3.5 Split-plot ANOVA table for TMA, TPC and H-ORAC$_{FL}$ values for frozen, large blueberries vacuum belt dried at RT=100°C.

		TMA		TPC		H-ORAC$_{FL}$
Source	df	p value	df	p value	df	p value
Whole Plots						
Rep	2		2		2	
Time	2	0.0034	2	0.0027	2	0.1962
Error	6		5		6	
Split Plots						
CT	2	<0.0001	2	0.9433	2	0.0178
Time*CT	4	0.0560	4	0.2894	4	0.0095
Error[a]	24		23		23	
Total	51		49		50	

[a] Split Plot Error used mean square (MS) for Rep*SubRep*Time*CT.

CHAPTER 4

THE ROLE OF PROCESSING CONDITIONS ON COLOR AND ANTIOXIDANT RETENTION OF JET-TUBE FLUIDIZED BED DRIED BLUEBERRIES[1]

[1] PALLAS, LAURA A., PEGG, RONALD B., SHEWFELT, ROBERT, and KERR, WILLIAM L. To be submitted to the *Journal of Food Processing and Preservation*.

Abstract

Jet-tube fluidized bed drying was studied as a means of rapidly producing shelf-stable and high-quality sweetened and non-sweetened blueberries. Sugar-infused and non-infused scarified Rabbiteye blueberries (*Vaccinium ashei* 'Brightwell') were dried at 99, 107, and 116 °C. Prior scarification of the blueberry surface decreased drying time. Increased lightness (L*) values were most notable at higher drying temperatures for sugar-infused blueberries, suggesting loss of pigments. Total monomeric anthocyanin content, initially 7.65 mg cyanidin-3-*O*-glucoside (C3G) eq./g extract, decreased as drying temperature increased, ranging between 4.07 mg C3G eq./g extract down to 1.51 mg C3G eq./g extract for dried blueberries. Total phenolics content increased with drying for non-infused blueberries to 31.6 mg gallic acid equivalents/g extract. With the exception of sugar-infused berries dried at 116 °C, dried blueberries maintained or had slightly increased oxygen radical absorbance capacity (H-ORAC$_{FL}$) values, showing their antioxidant capacity was retained upon drying. Drying at 107 °C for 75 min gave the shortest drying time with the best retention of blueberry flavor.

Practical Applications

Fluidized bed hot air drying (v_{air}~38 m/s) can continuously dry blueberries in less than 75 min to a_w< 0.50 and moisture content below 17.4 %. Scarification combined with sugar-infusion significantly reduces the drying time. Maintaining drying temperatures between 99-107 °C helps preserve the best color and flavor, maximizes consumer preference and maintains total phenolics and antioxidant capacity.

4.1 Introduction

Blueberry production in North America has grown from 211 million pounds in 1998 to 438 million pounds in 2010 (USDA, 2011). Less than half of harvested blueberries enter the fresh market, while approximately 56 % are processed by IQF or produced into juice, purees, dried fruit, or into dried ingredients. The demand for blueberries is expected to grow, as researchers have shown that various phytochemicals in blueberries are linked to reduced risk of cancer and heart disease, improved cognition, prevention of urinary tract disease and improved eye health (Camire, 2000). As the demand for, and production of, blueberries continues to increase, the need for extending their shelf life also will grow.

Dehydration is one of the most common methods for lengthening shelf life of fruits and vegetables. Dried blueberries, typically produced for direct consumption, are produced by infusion and osmodehydration with sugar solutions, followed by hot air drying. However, when subjected to high temperatures for substantial times, blueberry anthocyanins and flavonoids are compromised by subsequent degradation, and leaching of pigments into osmotic solutions can increase those losses. Substantial losses (~40 %) of anthocyanins were observed in blueberries dehydrated in a cabinet dryer at 90 °C; this increased to ~50 % when the blueberries had been previously treated in sugar solutions (Lohachoompol et al., 2004). Blueberries dried at 76 °C in a hot air convection dryer showed substantial reductions in total phenolics, anthocyanins and antioxidant activity (Mejia-Meza et al. 2008). Improved retention was found by using microwave-vacuum drying at 65 °C and 2.6 kPa. For Saskatoon berries, hot air drying was found to be most detrimental to inherent phytochemicals, followed by vacuum-microwave drying and freeze-drying. As the effect of high temperature on phenolic compounds depends on exposure time, means of reducing drying time should be beneficial. Mechanical abrasion has been shown

to reduce drying time in both blueberries and plums (Di Matteo et al., 2002; Lohachoompol, 2007). Another approach is to substantially increase air velocity. The effects of combining microwave radiation with spouted fluidized-bed drying of pre-frozen blueberries were reported by Feng et al (1999). The drying time was reduced to $1/24^{th}$ of that observed for tray drying. The berries had low bulk density, better rehydration properties and slightly redder color than those produced from non-combined spouted bed or tray drying.

A particular variant of fluidized-bed drying is the JetZone dryer (Kudra & Mujumdar, 2007). In this system, hot air is directed from above through a series of long tubes onto an oscillating solid conveyor surface, creating a bed of air surrounding each particle. The air rises and exits a cyclone that separates out fine particles. This creates a more uniform and controllable drying, with less jet clogging and the capability of creating multiple drying zones. Jet velocities up to 70 m/s can be attained with production rates from 90-41,000 kg/h.

The main objectives of this study were to identify processing conditions and treatments for drying blueberries in a JetZone fluidized bed dryer while maximizing quality and minimizing processing time. The effects of dryer temperature, pre-abrasion of the blueberries, osmodehydration with sugar solutions and blueberry size on drying time were determined. In addition, we studied the impact of drying conditions on color, sensory scores, anthocyanin and phenolic content, and antioxidant capacity.

4.2 Materials and Methods

4.2.1 Blueberry Preparation

Sizing. Fresh, ripe Rabbiteye blueberries (*Vaccinium ashei* 'Brightwell') were machine-harvested in 2008 in Alma, GA and donated by the Georgia Blueberry Growers Association. Individually quick frozen blueberries were stored at -20 °C. Frozen blueberries were sized using

a steel plate screen with 12.7 mm diameter perforations. Blueberries 12.7 mm or less in diameter were designated as “small” while those with diameter greater than 12.7 mm were designated as “large”.

Scarification. A portion of partially-thawed blueberries were mechanically scarified prior to drying to test if this improved sugar diffusion into the berry and moisture removal during drying. The equipment was constructed at the Bacon County Blueberry Research and Demonstration Farms in Alma, Georgia. Blueberries travelled on a moving belt under a row of circular blades, each of which had multiple cog-like extensions. The blades were set approximately 5 mm above the belt, which allowed the blades to perforate the blueberry skins.

Osmotic Dehydration. Partially-thawed blueberries (13.6 kg) were placed into a model LT-15 Vacuum Tumbler (Koch Equipment, Kansas City, MO) and the vacuum pulled to 88 kPa. A 60 % w/w aqueous sucrose solution was prepared at ~60 °C and added to the blueberries in a ratio of 1 kg of solution per kg of blueberries. The blueberries were tumbled at 8 to 10 rpm for 1 h. Samples were briefly washed with fresh cool water over a stainless steel mesh (size 10) sheet and allowed to drain to rinse excess sugar solution on the outside and thus reduce sugar buildup in the dryer.

4.2.2 JetZone Drying

Blueberry drying was carried out in a JetZone fluidized bed dryer (Model SNB 1.5x101, Wolverine Proctor & Schwartz, Inc. Merrimac, MA) with one recirculation zone and a smooth, non-perforated, stainless-steel-hinged, slat-type belt (Figure 4.1). Steel mesh cages, through which air could pass, helped contain the berries but still allowed them to tumble and fluidize. Drying was conducted at air temperatures of 99 °C, 107 °C or 116 °C. Air velocity was calculated based on the pressure drop (ΔP), as measured by an integrated manometer, across the

jet tube exit and the surrounding air. In this case, the velocity of the highest speed air near the tube opening is:

$$v = \sqrt{\frac{\Delta P}{\rho_a}} \tag{1}$$

where the density of air (r_a) can be calculated by:

$$\rho_a = \frac{(1.293^{kg}/_{m^3})(273K)}{(273K + T)} \tag{2}$$

With a pressure drop of 1338 Pa, air velocities ranged from 37.5 m/s at 99 °C to 38.4 m/s at 116 °C.

4.2.3 Moisture Content

The moisture content (MC) of fresh and dried blueberries was determined according to AOAC Method 934.06 (AOAC International, 1995) with modifications. Five blueberries were cut in half using a razor blade and weighed in pre-dried aluminum weighing dishes (Fisher Scientific). Samples were dried in a Model 1430MS vacuum oven (VWR International, West Chester, PA) at 70 °C and 40 kPa for 24 h, or until a constant mass was achieved. The MC was determined in triplicate per drying batch.

4.2.4 Water Activity

For water activity (a_w), three to five blueberries were cut in half and placed in a sample cup. The a_w was determined using an AquaLab Model CX-2 (Decagon Devices Inc, Pullman, WA) at 25 ± 3 °C; a_w measurements were performed in triplicate per drying batch.

4.2.5 Phytochemical Analysis

Extractions. Samples, previously stored at -80 °C, were lyophilized in a Freezemobile 25 SL Unitop 600L (Virtis Company, Gardiner, NY) at vacuum less than 26 Pa. Samples were

placed onto conduction plates at -45 °C, and the vacuum initiated once the internal blueberry temperature reached -40 °C. The plate temperature was increased to 30 °C and the blueberries were dried until the internal berry temperature reached 27 °C. All samples were lyophilized prior to extraction to eliminate differences in moisture content between samples and thus variations in extraction efficiency.

Dried blueberries were ground in a coffee mill (Kitchen Aid, St. Joseph, MI). Blueberry powder and 80 % (v/v) aqueous acetone (1:10 w/v, respectively) were mixed in a 250 mL Erlenmeyer flask, which was loosely covered with aluminum foil and placed in an orbital shaker water bath (Model G76, New Brunswick Scientific, New Brunswick, NJ) at 45 °C for 30 min. After this period, the filtrate was passed through P8 filter paper (Fisher Scientific) into a second Erlenmeyer flask. The recovered sediment was then extracted twice more with 80 % (v/v) aqueous acetone as described above, each time pooling the filtrate. Acetone was removed from the filtrate using a R-210 Büchi Rotovapor (Büchi Corporation, New Castle, DE) at 40 °C; the evaporator was connected to a V-700 vacuum pump and V-850 controller (Büchi) set for 190 mbar. The aqueous residue was transferred to an aluminum dish, frozen and then lyophilized for 24 h to obtain a dry extract. Extracts were scraped and transferred to small vials and then sealed under a nitrogen headspace. Dry extracts were stored in a refrigerator until further analyzed.

Total Monomeric Anthocyanins. The pH-differential method described by Giusti and Wrolstad (2001) was used to determine the total monomeric anthocyanins (TMA) content in the dried blueberry preparations. Briefly, this method is based on a reversible color change of monomeric anthocyanin pigments with an alteration in the pH; that is, the colored oxonium-ion form exists at pH 1.0, and the colorless hemiketal form predominates at pH 4.5. The difference in absorbance of the pigments at $\lambda = 510$ nm is proportional to the anthocyanin concentration;

results were expressed as cyanidin-3-*O*-glucoside (C3G) equivalents, as C3G is a dominant anthocyanin in blueberries. Two buffer systems were employed in the assay: a 0.025 M potassium chloride buffer, pH 1.0, and a 0.4 M sodium acetate buffer, pH 4.5. Dried blueberry samples were dissolved in pH 1.0 and pH 4.5 buffers from an original concentration of ~1 mg/mL with a dilution factor of 7. After an incubation period of 15 min at room temperature to allow for optimal color development, absorbance readings were taken at λ = 510 and 700 nm with a 8453 UV-visible spectrophotometer (Agilent Technologies, Wilmington, DE). The pH differential absorbance was determined as follows:

$$Abs = (A_{510nm} - A_{700nm})_{@\ pH\ 1.0} - (A_{510nm} - A_{700nm})_{@\ pH\ 4.5} \qquad (1)$$

The TMA content was calculated using the following equation:

$$TMA(mg\ C3G\ eq\ /\ L) = \frac{Abs \times MW \times DF \times 1000}{\varepsilon \times \ell} \qquad (2)$$

where A = absorbance; MW = molecular weight (449.2 g/mol); DF = dilution factor; and ε = molar extinction coefficient (25,740 L cm^{-1} mol^{-1}). For easier comparison to literature values, the TMA content was calculated as mg C3G equivalents per g of extract and per g of dry matter (DM).

Total Phenolics Content. The TPC of extracts was determined using Folin-Ciocalteu's phenol reagent as described by Singleton et al. (1999) with modifications for a FLUOstar Omega microplate reader (BMG Labtech, Raleigh, NC). Gallic acid was employed as the standard. After the colorimetric reaction and a 60 min holding period, sample absorbance was measured at 750

nm in a flat-bottomed, clear polystyrene, 96-well plate (Fisher Scientific) in the FLUOstar Omega microplate reader, with path length correction selected prior to running the program. Each sample absorbance was measured in duplicate and averaged, and each extract was measured in triplicate. Results were calculated and reported as mg of gallic acid equivalents (GAE) per g of extract and per g DM.

Hydrophilic-Oxygen Radical Absorbance Capacity *(H-ORAC$_{FL}$)*. H-ORAC$_{FL}$ of blueberry extracts was determined as described by Prior et al. (2003) with modifications for a FLUOstar Omega microplate reader. Extracts were reconstituted with deionized water, vortexed until particles dispersed, and centrifuged (Centrific Model 228, Fisher Scientific) for 5 min to remove any particulate fines. The assay was carried out in a flat, clear-bottomed 96 well black plate (Costar #3631, Corning, Inc., Corning, NY). Except for the outside wells, each well received either 20 μL of diluted aqueous extract, 20 μL of Trolox (6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid) at concentrations of 6.25, 12.5, 25, 50, and 100 μM, or 40 μL of 75 mM phosphate buffer (pH 7.4) as the blank solution. The microplate reader was programmed to add 400 μL of fluorescein (0.11 μM), followed by 150 μL of 2,2′-azobis(2-amidinopropane) dihydrochloride (AAPH) (31.6 mM, Sigma-Aldrich Chemical Co., St. Louis, MO) to each well. All solutions had been previously incubated at 37 °C. The excitation wavelength was set at 485 nm. Emission was recorded at 520 nm after the addition of fluorescein and AAPH and every 192 s thereafter, until a 95 % loss of the fluorescence was noted (~ 3 h). Results were calculated based on the fluorescein decay by calculating areas under the curves (AUC) for the phosphate buffer blanks, aqueous blueberry extract samples, and Trolox standards. A standard curve was obtained by plotting the known concentrations of Trolox against the respective AUC for each standard concentration. Final H-ORAC$_{FL}$ values were calculated

using the regression equation of the standard curve expressed as μmol Trolox equivalents (TE) per g of extract and per 100 g of FW.

4.2.6 Color

Blueberry color was measured using a Chroma Meter (Model CR-410, Konica Minolta, Ramsey, NJ) equipped with a 50 mm aperture and calibrated with a white standard tile. A 325 mL Pyrex dish (3140-100, Corning Inc., Corning, NY) was filled with dried blueberries. Two color measurements were averaged per sample, differing by 180 degree rotation of the sample dish.

4.2.7 Sensory Analysis

Experienced Sensory Panels. An experienced panel consisting of ten members evaluated the dried blueberry samples based on a 5-point intensity scale for selected sensory descriptors: color (slightly blue to very blue), degree of shrivel (negligible to intense), sweetness (not sweet to extremely sweet), blueberry flavor intensity (negligible to intense), firmness (soft to very firm), moistness (dry to very moist), grittiness (negligible to very gritty), tooth compaction (negligible to intense), and presence of off-flavors (negligible to intense). All sensory evaluation protocols, advertisements, and handling of research data were approved by the University of Georgia's Institutional Review Board.

Panelists were assembled prior to evaluation and each test attribute was discussed to ensure all agreed and understood the definition of each attribute. Sample evaluation was conducted in a sensory laboratory equipped with individual testing booths having white fluorescent lighting. Panel evaluation was performed in one day. Three unsweetened samples were evaluated and then followed by three sweetened samples.

Consumer Preference Testing. Consumer testing was performed to determine if drying conditions affected preference for the different dried blueberries. Preference tests using 50 panelists were conducted in one day at the University of Georgia sensory testing laboratory. For each test, consumers first were presented with three unsweetened dried blueberry samples with each sample representing a particular drying temperature treatment. Panelists also were presented with water and unsalted crackers to cleanse the palate between samples. Panelists were asked to taste the samples and rank their preference from most preferred to least preferred. Panelists were then presented with three sweetened and dried blueberry samples in the same manner, and asked to taste and rank their preference for the three sweetened samples from most to least preferred.

4.2.8 Statistical Analysis

The experiment was limited to a maximum of five treatments in the dryer at one time, where the treatment groups were separated by the screen enclosures. Thus, a half-fractional factorial experiment was used to assess several drying factors, including berry size (small versus large), prior scarification (with or without), prior infusion (no infusion versus sugar-infused) and three drying temperatures (210 °F = 99 °C, 225 °F = 107 °C and 240 °F = 116 °C). Mean differences were tested for significance at the 5 % level using the least significant difference (LSD) test.

4.3 Results and Discussion

4.3.1 Moisture Properties

Typically, fruits are dried to an a_w below 0.6 for ready-to-eat products, and below 0.3 for fully dried, low-moisture products. Figure 4.2 shows how a_w changed with drying time. At 99 °C, blueberries took at least 75 min to reach a_w= 0.6, and after 100 min had reached an a_w= 0.53. At 107 °C, the a_w reached 0.6 at ~60 min and 0.48 at 75 min. At 116 °C, the a_w reached 0.6 by

~45 mins and 0.49 after 50 mins. Drying time was relatively short compared to several other types of drying. Beaudry et al. (2004) reported on hot air drying of osmotically treated *Vaccinium macrocarpon* (cranberry). At 62 °C and an air velocity of 1 m/s, berries took on the order of 8-12 h to reach a 15 % moisture content. The time was reduced by about half by using microwave radiation to assist the process. Lohachoompol et al. (2007) studied quality changes in blueberries dried in hot air. Treatments included multiple drying stages: 90 °C for 90 min, then 70 °C for 120 min, and 50 °C until samples reached a_w= 0.60-0.65 (typically 15-24 h). Mechanically abraded samples had somewhat shorter drying times. Alternatively, samples were dried at low temperature (30 °C and 50 °C at 10 % RH) in a heat pump dryer. In the latter case, drying time varied between 2-10 days.

Infusion with sugars was a significant factor in determining the time to reach a_w< 0.6. Pretreatment in 60 % sucrose did not significantly decrease drying time for samples dried at 107 °C or 116 °C (Figure 4.2). With air at 99 °C, however, infused blueberries had lower a_w at times between 30 and 75 min, but there was no difference in a_w after 100 min. Changrue et al. (2008) reported that osmotic dehydration prior to microwave-vacuum drying of strawberries did not reduce drying time, but did improve the quality of the dried product. They suggested that sugar infusion may impede coupling with the microwave energy. However, (Grabowski et al., 2002) showed that osmotic pretreatment of cranberries reduces drying rates during the second drying period for several dryer types.

As drying runs were based around a fractional factorial designs, several of the factors were confounded into alias pairs including (infusion, size*scarification), (scarification, size*infusion), and (size, scarification*infusion), with the defining contrast being infusion*scarification*size. While infusion was a significant factor, the alias pair to infusion

(size*scarification) may also be significant. Blueberry size was also found to be a significant factor, or its alias pair (scarification*infusion). Our conjecture is that the alias pair scarification*infusion is likely the significant effect as the size differential was not sufficient to impact the drying time, especially for drying times less than 100 min. As previously noted, scarification combined with infusion likely would decrease drying time by allowing more effective moisture diffusion out of the berry, even before air drying, and increasing product solids as sugar diffuses into the blueberry. Scarification alone was not significant, thus likely affecting the drying time only when paired with infusion.

4.3.2 Color

Table 4.1 shows the color values for the dried blueberries. With some exceptions, most treatment groups had different color values than others. The lightness value (L*) increased somewhat with temperature. For example, L* was 18.20 and 17.8 for non-infused and infused berries dried at 99 °C, while those dried at 116 °C had values of 19.70 and 20.90. An increase in the L* value indicates a lighter color, most likely related to a loss in anthocyanins, compounds responsible for the characteristic color in blueberries. Yang and Atallah (1985) reported an increase in L* values for blueberries dried by freeze-, forced air, vacuum oven, and micro-convection drying when compared to frozen blueberries. Heat degradation of pigments during drying also has been shown to increase the lightness of strawberries and blueberries (Contreras et al., 2008; Yang & Atallah, 1985).

Dried blueberry hue angle (h) values ranged from 310.3 ° to 331.0 °, with the infused blueberries dried at the highest temperature having the smallest hue angle, and non-infused blueberries dried at the lowest temperature having the greatest hue angle. These values represent hues in the purple region between blue and red. At each temperature, non-infused dried

blueberries exhibited a higher hue angle than infused blueberries. This may be due to the loss of some water-soluble pigments that diffused out into the sugar solution during the osmotic pretreatment.

4.3.3 Sensory Analysis

Experienced Panel. The results from the experienced taste panel (Table 4.2) show that sweetened dried blueberries did not have a significant difference between the means for blueberry flavor intensity at the three different drying temperatures (99, 107, and 116 °C), but the unsweetened dried blueberries did. Blueberries dried at 116 °C without infusion had lower blueberry flavor intensity than those dried at 99 and 107 °C. Feng et al. (1999) found that increased temperature altered the aroma compounds in 'Elliot' blueberry juice.

The firmness for the infused blueberries dried at 99 °C was similar to infused berries dried at 107 °C but significantly different from blueberries dried at 116 °C. The a_w was slightly higher (0.530) for the 99 °C sweetened dried blueberries compared to the a_w (0.489) of the sweetened blueberries dried at 116 °C (Figure 4.2). All other sensory characteristics including sweetness, moistness, crunchiness, and tooth compaction were not significantly different for blueberries dried at the three temperatures for either unsweetened or infused fruit.

Consumer Panel. Fifty consumer panelists ranked the blueberries dried at the three different temperatures. For 50 panelists ranking 3 products, the Basker critical value of difference among rank sums was 23. Sweetened blueberries dried at 99 °C had a rank sum of 100, while those at 107 °C had a rank sum of 95, and at 116 °C a rank sum of 105. For unsweetened dried blueberries the rank sums for berries dried at 99 °C, 107 °C and 116 °C were 99, 94 and 107, respectively. While in both cases berries dried at 107 °C were the highest ranked, the differences with berries from other groups were not significant at $p<0.05$. Based on the

consumer sensory rank and experienced panel for blueberry flavor intensity, drying temperatures below 116 °C would result in best blueberry flavor and consumer desirability. Drying at 107 °C would provide faster production rates than drying at 99 °C.

4.3.4 Phytochemical Analysis

Changes in phytochemicals during drying were assessed by total monomeric anthocyanins, total phenolics content, and hydrophilic-oxygen radical absorbance capacity (Table 4.3). Values are presented per gram of extract and per 100 g fresh weight.

Total Monomeric Anthocyanins. The total monomeric anthocyanins (TMA) in the dried blueberries were all less than values before drying (Table 4.3). Initial values for frozen blueberries before drying were 7.65 mg C3G eq./g extract (89.9 mg C3G eq./100g FW or 508 mg C3G eq./100g dry matter). This is most similar to values (530 mg C3G eq./100g dry matter) reported by Vaghri et al. (2000) for the Northern highbush variety 'Hardy Blue'. Values were less than those reported by Moyer et al. (2002) and Scibisz and Mitek (2007) but slightly higher than those measured by Prior et al. (1998) for 'Brightwell' blueberries (61.8 mg C3G eq./100g FW).

The combined treatments of osmotic dehydration followed by hot air drying at 107 °C and 116 °C resulted in the greatest loss in TMA. As the drying temperature increased, TMA values decreased. For example, for non-infused berries, the TMA were 7.65 mg C3G eq./g extract. At 99, 107 and 116 °C, these values were 4.07, 3.32 and 2.51 g C3G eq./g extract. Depending on drying temperature and infusion, this represented a 47 to 81 % loss in anthocyanin content after drying was completed, with higher temperatures and sugar infusion generating the greatest loss. Exposure to elevated temperatures for prolonged periods is known to break down anthocyanins, with compounds such as cyanidin-3-*O*-glucoside and pelargonidin-3-*O*-glucoside

being particularly susceptible to heat (Sadilova et al., 2007). At pH 3.5, breakdown products include chalcone glycosides upon scission of the flavylium backbone, with concomitant loss of color. In this study, TMA values were correlated with the color values L* (r^2=0.87), chroma (r^2=0.85), and h (r^2=0.84). It should be noted that some heating may be necessary for preservation of blueberry color and phytochemicals, particularly if cellular structure has been compromised and the product is exposed to oxygen. Without blanching or related heat treatment, polyphenol oxidase and related enzymes may become active, which leads to polymerization of phenolic compounds and formation of brown pigments. Vaghri et al. (2000) found 50-60 % reduction in TMAs, depending on variety, for samples dried in hot air at 70 °C for 12.5 h. Lohachoompol et al. (2004) reported 41 % reduction in anthocyanin content for untreated dried blueberries dried at 90 °C and 49 % loss in anthocyanin content for sweetened dried blueberries. Kwok et al. (2004) reported 83 % loss in anthocyanin content of dried Saskatoon berries dried at 70 °C for 3 d.

Total Phenolics Content. Prior to drying, the TPC of the blueberries was 24.9 mg GAE/g extract (293 mg GAE/100g FW). Despite the decrease in anthocyanins during drying, there was no significant change in TPC for any treatment on a 100 g fresh weight basis (Table 4.3). Non-infused dried blueberries had 20-30 % higher phenolics content compared to infused blueberries dried at the same temperatures. For example, at drying temperatures of 99 °C, non-infused berries had 302 mg GAE/100g FW while infused berries had 290 mg GAE/100g FW. One reason for the greater TPC in non-infused berries is that some compounds likely diffused into the sugar solutions used in osmodehydration. Alternatively, the infusion of sugar into the fruit may have provided some protection against thermal degradation.

The total phenolics content of blueberries in this study were comparable to that reported by Prior et al. (1998) of 271.4 mg GAE/100 g FW for 'Brightwell' fresh blueberries. Larrauri et al. (1997) reported a significant decrease in total extractable polyphenols for grape pomace dried at 100 °C (3.5 h) and 140 °C (3 h), but no changes for samples dried at 60 °C (8 h). Kwok et al. (2004) found up to 65 % reduction in TPC for Saskatoon berries dried at 75 °C for 3 d as compared to fresh berries, but little changes in berries processed by vacuum-microwave drying or freeze-drying. Mejia-Meza et al. (2008) dried blueberries 4.5 h at 76.6 °C to 5 % MC and reported no difference between the TPC of hot air dried blueberries and fresh blueberries. Most of the previously reported literature has dried blueberries for longer than 3 hours whereas the work reported in this study dried blueberries in 50 to 100 min.

Oxygen Radical Absorbance Capacity. H-ORAC$_{FL}$ values varied significantly amongst drying treatments (Table 4.3). In general, sugar-infused blueberries had lower H-ORAC$_{FL}$ values than infused berries at the respective drying temperatures. Prior to drying, infused berries had H-ORAC$_{FL}$ values of 296.1 μmol TE/g extract (3480 μmol TE/100 g FW), while infused berries had H-ORAC$_{FL}$ values of 269.6 μmol TE/g extract (3410 μmol TE/100g FW). This suggests that some of the water-soluble antioxidants diffused out of the berries during the treatment in sugar solutions.

Infused berries dried at the highest temperature (116 °C) had the lowest H-ORAC$_{FL}$ of 219 μmol TE/g extract. Overall, H-ORAC$_{FL}$ values for blueberries dried at or less than 107 °C for less than 75 min were comparable to fresh blueberries. H-ORAC$_{FL}$ values were most correlated with TPCs (r^2=0.80).

Vaghri et al. (2000) measured higher antioxidant activities in vacuum-microwave dried and freeze-dried blueberries as compared to blueberries hot air dried at 70 °C for 12.5 h. Kwok et

al. (2004) reported significant reduction in radical scavenging capacity of hot air dried Saskatoon berries as compared to fresh blueberries. Kalt et al. (2000) measured 52.9 mmol TE/100 g DW in fresh blueberries, 25.5 mmol TE/100 g DW for intermediate-moisture dried fruit, 15.1 mmol TE/100 g DW for low-moisture dried fruit, and 11.3 mmol TE/100 g DW for sugar-infused/dried fruit.

4.4 Conclusions

The JetZone fluidized bed dryer successfully dehydrated both infused and non-infused blueberries to a_w less than 0.55 in 50-100 min depending drying temperature. Drying at 107 °C resulted in the shortest drying time that maintained blueberry flavor and high consumer preference. Scarification and sugar infusion were significant factors that influenced drying time and blueberry quality. Higher drying temperatures reduced anthocyanin content, but total phenolics content and oxygen radical absorbance capacity remained relatively unchanged or even higher than that of fresh non-dried blueberries.

References

AOAC International, (1995). *Official Methods of Analysis* (16th ed). Association of Official Analytical Chemists International, Arlington, Virginia.

Beaudry, C., Raghavan, G.S.V., Ratti, C. & Rennie, T.J., (2004). Effect of four drying methods on the quality of osmotically dehydrated cranberries. *Drying Technology* 22(3), 521-539.

Camire, M.E., (2000). Bilberries and blueberries as functional foods & pharmaceuticals., in: Mazza, G. & Ooomah, B.D. (Eds.), *Functional foods: herbs, botanicals and teas*. Technomic Press, Lancaster, Pa, pp. 289-319.

Changrue, V., Orsat, V. & Raghavan, G.S.V., (2008). Osmotically dehydrated microwave-vacuum drying of strawberries. *Journal of Food Processing and Preservation* 32(5), 798-816.

Contreras, C., Martin-Esparza, M.E., Chiralt, A. & Martinez-Navarrete, N., (2008). Influence of microwave application on convective drying: Effects on drying kinetics, and optical and mechanical properties of apple and strawberry. *Journal of Food Engineering* 88(1), 55-64.

Di Matteo, M., Cinquanta, L., Galiero, G. & Crescitelli, S., (2002). Physical pre-treatment of plums (*Prunus domestica*). Part 1. Modelling the kinetics of drying. *Food Chemistry* 79(2), 227-232.

Feng, H., Tang, J.M., Mattinson, D.S. & Fellman, J.K., (1999). Microwave and spouted bed drying of frozen blueberries: The effect of drying and pretreatment methods on physical properties and retention of flavor volatiles. *Journal of Food Processing and Preservation* 23(6), 463-479.

Giusti, M.M. & Wrolstad, R.E., (2001). Characterization and measurement of anthocyanins by spectroscopy. Unit F1.2, in: Wrolstad, R.E. (Ed.), *Current Protocols in Food Analytical Chemistry*. John Wiley & Sons, Inc., New York, pp. F1.2.1-F1.2.13.

Grabowski, S., Marcotte, M., Poirier, M. & Kudra, T., (2002). Drying characteristics of osmotically pretreated cranberries - Energy and quality aspects. *Drying Technology* 20(10), 1989-2004.

Kalt, W., McDonald, J.E. & Donner, H., (2000). Anthocyanins, phenolics, and antioxidant capacity of processed lowbush blueberry products. *Journal of Food Science* 65(3), 390-393.

Kudra, T. & Mujumdar, A.S., (2007). Special drying techniques and novel dryers, in: Mujumdar, A.S. (Ed.), *Handbook of Industrial Drying*, 3rd edition ed. Taylor & Francis, Boca Raton, FL, pp. 453-517.

Kwok, B.H.L., Hu, C., Durance, T. & Kitts, D.D., (2004). Dehydration techniques affect phytochemical contents and free radical scavenging activities of Saskatoon berries (*Amelanchier alnifolia* Nutt.). *Journal of Food Science* 69(3), 122-126.

Larrauri, J.A., Ruperez, P. & Saura-Calixto, F., (1997). Effect of drying temperature on the stability of polyphenols and antioxidant activity of red grape pomace peels. *Journal of Agricultural and Food Chemistry* 45(4), 1390-1393.

Lohachoompol, V., (2007). Effects of drying on anthocyanins in blueberries. *Food Science and Technology, School of Chemical Sciences and Engineering*. The University of New South Wales, Sydney, Australia.

Lohachoompol, V., Srzednicki, G. & Craske, J., (2004). The change of total anthocyanins in blueberries and their antioxidant effect after drying and freezing. *Journal of Biomedicine and Biotechnology* 2004(5), 248-252.

Lohachoompol, V., Srzednicki, G. & Mulholland, M., (2007). Effects of pre-treatments on drying kinetics and anthocyanin content in dried blueberries, in: Chen, G. (Ed.), *5th Asia-Pacific Drying Conference*, Hong Kong, pp. 1077-1084.

Mejia-Meza, E.I., Yanez, J.A., Davies, N.M., Rasco, B., Younce, F., Remsberg, C.M. & Clary, C., (2008). *Improving nutritional value of dried blueberries (Vaccinium corymbosum L.) combining microwave-vacuum, hot-air drying and freeze drying technologies*. Journal 4(5), article 5. Online: http://www.bepress.com/ijfe/vol4/iss5/art5/

Moyer, R.A., Hummer, K.E., Finn, C.E., Frei, B. & Wrolstad, R.E., (2002). Anthocyanins, phenolics, and antioxidant capacity in diverse small fruits: *Vaccinium*, *Rubus*, and *Ribes*. *Journal of Agricultural and Food Chemistry* 50(3), 519-525.

Prior, R.L., Cao, G.H., Martin, A., Sofic, E., McEwen, J., O'Brien, C., Lischner, N., Ehlenfeldt, M., Kalt, W., Krewer, G. & Mainland, C.M., (1998). Antioxidant capacity as influenced by total phenolic and anthocyanin content, maturity, and variety of Vaccinium species. *Journal of Agricultural and Food Chemistry* 46(7), 2686-2693.

Prior, R.L., Hoang, H., Gu, L.W., Wu, X.L., Bacchiocca, M., Howard, L., Hampsch-Woodill, M., Huang, D.J., Ou, B.X. & Jacob, R., (2003). Assays for hydrophilic and lipophilic antioxidant capacity (oxygen radical absorbance capacity (ORAC(FL))) of plasma and other biological and food samples. *Journal of Agricultural and Food Chemistry* 51(11), 3273-3279.

Sadilova, E., Carle, R. & Stintzing, F.C., (2007). Thermal degradation of anthocyanins and its impact on color and in vitro antioxidant capacity. *Molecular Nutrition & Food Research* 51(12), 1461-1471.

Scibisz, I. & Mitek, M., (2007). The changes of antioxidant properties in highbush blueberries (*Vaccinium corymbosum* L.) during freezing and long-term frozen storage. *Acta Scientiarum Polonorum - Technologia Alimentaria* 6(4), 75-81.

Singleton, V.L., Orthofer, R. & Lamuela-Raventos, R.M., (1999). Analysis of total phenols and other oxidation substrates and antioxidants by means of Folin-Ciocalteu reagent. *Methods in Enzymology* 299, 152-178.

USDA, (2011). Noncitrus fruits and nuts: 2010 summary. *National Agricultural Statistics Service*.

Vaghri, Z., Scaman, C.H., Kitts, D.D., Durance, T. & McArthur, D.A., (2000). Quality of the vacuum microwave dried blueberries in terms of color, composition, and antioxidant activity, *12th International Drying Symposium*, paper 318 ed. Elsevier Science, Amsterdam, pp. 1-10.

Yang, C.S.T. & Atallah, W.A., (1985). Effect of 4 drying methods on the quality of intermediate moisture lowbush blueberries. *Journal of Food Science* 50(5), 1233-1237.

Figures and Tables

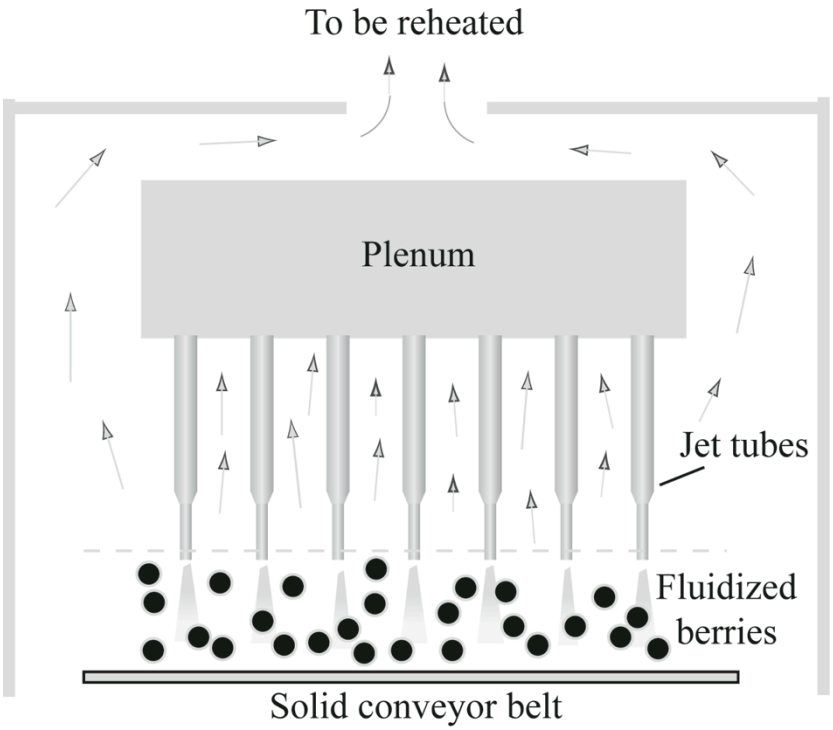


Figure 4.1 Section of the JetZone fluidized bed dryer.

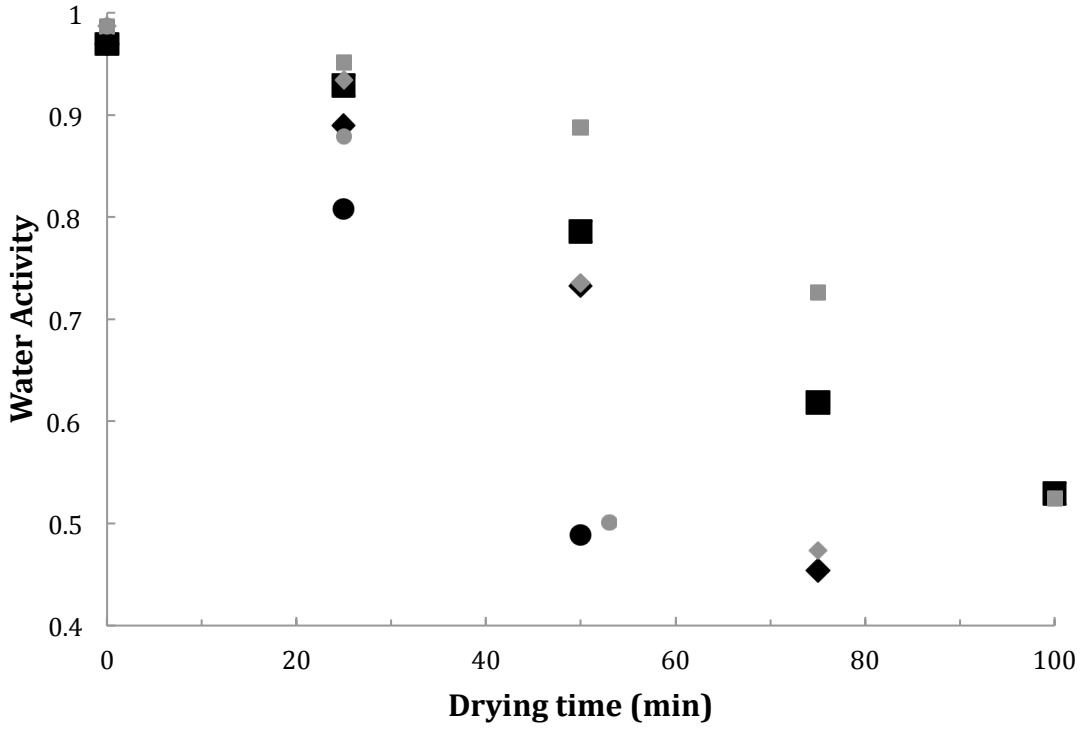


Figure 4.2 The effect of drying time on large, scarified berries (with and without sugar infusion) at drying temperatures of 99 °C, 107 °C and 116 °C. ■-99 °C, ■-99 °C infused, ◆-107 °C, ◆-107 °C infused, ●-116 °C, ●-116 °C infused.

Table 4.1 Mean color values of fluidized bed dried blueberries with and without sugar infusion at various drying temperatures.

Drying Temp (°C)	Treatment	*L**		*c*		*h*	
99	Non-Infused	18.20	c,d	2.36	c	331.0	a
99	Infused	17.80	d	2.26	d	326.9	c
107	Non-Infused	18.70	c	2.33	c	328.4	b
107	Infused	21.40	a	2.52	b	320.5	e
116	Non-Infused	19.70	b	2.55	b	324.0	d
116	Infused	20.90	a	2.85	a	310.3	f

Means within a column followed by the same letter are not significantly different ($p < 0.05$).

Table 4.2 Experienced panel mean responses and consumer preference rank totals for dried blueberries with and without sugar infusion at varying drying temperatures.

	Sweetened			Unsweetened		
	Drying Temperature					
	99°C	107°C	116°C	99°C	107°C	116°C
Attribute						
Color	4.5	4.4	4.7	4.7	4.8	4.8
Shrivel	3.9	3.8	3.8	3.8	3.7	4.0
Sweetness	3.1	2.8	2.7	2.9	2.7	2.4
Blueberry Flavor	3.6	3.5	2.9	3.4	3.2	2.0
Firmness	2.5	2.8	3.5	3.5	3.3	2.9
Moistness	3.3	2.4	2.3	1.8	2.1	2.2
Grittiness	3.2	3.1	3.7	4.0	3.3	3.5
Tooth Compaction	2.8	2.6	3.3	2.8	3.0	3.3
Off Flavors	2.5	1.8	2.5	3.1	2.2	2.4

Drying Temperature	Rank Sum Sweetened	Rank Sum Unsweetened
99°C	100	99
107°C	95	94
116°C	105	107

Table 4.3 Total anthocyanins (TMA), phenolics (TPC) and antioxidant capacities (H-ORAC$_{FL}$) of fresh and Jet-tube fluidized bed dried blueberries to a_w <0.55 at various drying temperatures.

Treatment [1] (Infused-°C)		Anthocyanin [2] (mg C3G eq./ g extract)		Phenolics [3] (mg GAE/g extract)		H-ORAC$_{FL}$ [4] (µmol TE/g extract)	
Non-infused	**ND**	7.65 ± 0.10	b	24.9 ± 4.9	c	296.1 ± 5.9	c,d
Infused	**ND**	8.10 ± 0.14	a	24.4 ± 3.8	b,c	269.6 ± 55.9	d,e
Non-infused	**99**	4.07 ± 0.06	c	31.1 ± 4.7	a,b	358.7 ± 36.3	a,b
Infused	**99**	3.78 ± 0.09	c	26.0 ± 5.7	a,b,c	337.7 ± 30.9	b,c
Non-infused	**107**	3.32 ± 0.28	d	31.6 ± 11.2	a	374.4 ± 19.9	a,b
Infused	**107**	2.25 ± 0.21	e	25.9 ± 2.8	a,b,c	287.3 ± 27.3	c,d
Non-infused	**116**	2.52 ± 0.27	e	31.2 ± 4.3	a,b	406.7 ± 61.1	a
Infused	**116**	1.51 ± 0.16	f	24.1 ± 6.3	c	219.3 ± 10.4	e
Treatment (Infused-°C)		**Anthocyanin (mg C3G eq./ 100g FW)**		**Phenolics (mg GAE/100g FW)**		**H-ORAC$_{FL}$ (µmol TE/100g FW)**	
Non-infused	**ND**	89.9 ± 1.2	b	293 ± 57	a	3480 ± 70	a,b
Infused	**ND**	103.0 ± 1.8	a	309 ± 48	a	3410 ± 710	a,b,c
Non-infused	**99**	39.6 ± 0.6	c	302 ± 46	a	3480 ± 350	a,b
Infused	**99**	42.1 ± 1.0	c	290 ± 64	a	3760 ± 340	a
Non-infused	**107**	33.1 ± 2.8	d	271 ± 32	a	3730 ± 200	a
Infused	**107**	22.8 ± 2.1	e	263 ± 28	a	2910 ± 280	b,c
Non-infused	**116**	25.0 ± 2.6	e	309 ± 43	a	4030 ± 610	a
Infused	**116**	19.1 ± 2.0	f	306 ± 80	a	2780 ± 130	c

Means within the column followed by the same letter are not significantly different ($p < 0.05$).

[1] Treatments: ND, non-dried; 99, 107, 116°C fluidized bed drying temperatures at air velocity ~38 m/s. [2] Concentration based on C3G equivalents per g of dry extract and per 100 g of FW fruit. [3] Concentration based on gallic acid equivalents per g of dry extract and per 100 g of FW fruit. [4] Expressed in micromoles Trolox equivalents per g of extract and 100 g of FW.

CHAPTER 5

QUALITY ASPECTS OF JETZONE FLUIDIZED BED DRIED RABBITEYE BLUEBERRIES[1]

[1] PALLAS, LAURA A., PEGG, RONALD B., SHEWFELT, ROBERT, and KERR, WILLIAM L. To be submitted to *LWT- Food Science and Technology*.

Abstract

Five cultivars of rabbiteye blueberries (*Vaccinium ashei* Reade cv. 'Premier', 'Tifblue', 'Brightwell', 'Alapaha', and 'Powderblue') were dried in a JetZone fluidized bed air dryer with varying pretreatments including mechanical abrasion and osmotic dehydration. Moisture content, water activity (a_w), color, anthocyanin content, phenolic content, and antioxidant capacity were measured for the dried blueberries. In addition, experienced panelists rated various quality attributes and a consumer panel was used to determine preference. Vacuum osmotic dehydration for 70 min using a 60 °Brix sugar solution achieved similar moisture contents to soaking blueberries 24 h at atmospheric conditions. Drying time ranged from 66 – 95 min at 107 °C and v_{air}=38 m/sec, achieving a final water activity of 0.347 – 0.605. Prior osmotic dehydration reduced the drying time. While drying reduced the monomeric anthocyanin content, total phenolics content and antioxidant capacity increased after drying. 'Premier' was the most preferred vacuum infused dried blueberry with a_w of 0.53 and 15.7 % moisture. 'Tifblue' was most preferred among the overnight infused and also unsweetened dried blueberries.

5.1 Introduction

Blueberries are a sweet, flavorful fruit grown extensively in North America, but with burgeoning markets in South America and Asia. Rabbiteye blueberries (*Vaccinium ashei* Reade) are particularly suited for growth in the southeastern United States as they are resistant to native pests and have lower chilling requirements. There are many rabbiteye cultivars, however, that vary in size, color, sweetness and time of harvest. The berries are readily recognized by their distinctive blue-red color, which derives primarily from the anthocyanins they contain. These anthocyanins and other phenolic compounds are believed to be the main contributors to the health benefits of blueberries (Kong et al., 2003; Zafra-Stone et al., 2007) and have been studied for their role in improving cognition and memory, preventing urinary tract infections, reducing cancer risk, improving vision health and limiting cardiovascular disease (Camire et al., 2002).

The limited season and short shelf life of blueberries creates excess fruit, and those harvests not destined for the fresh market are frozen, processed into juices and canned products, or dried into a variety of products. Drying has been a successful way of preserving blueberries, with reduced-moisture (a_w<0.6) fruit used for direct consumption or as part of snack mixes, and low-moisture (a_w<0.3) fruit used for dry mixes, powdered ingredients or as supplements. Drying times can be significant, ranging from a few hours to several days, and changes can occur in quality and nutritional aspects of the fruit. Due to the potential health benefits of antioxidants, it is critical to measure their changes during processing to better assess the nutritional value of processed products (Skrede et al., 2000).

A variety of drying methods are employed to produce dehydrated blueberry products, including solar, hot air, microwave, osmotic, freeze, vacuum and spray drying (Stojanovic & Silva, 2007). The most common method of dehydrating blueberries is hot air drying. Typically,

those methods that expose the berries to high temperatures for longer times are most detrimental to nutritional and quality factors (Lohachoompol, 2007; Stojanovic & Silva, 2007). For example, when highbush blueberries were dried several hours in a cabinet dryer, including 90 min at 90 °C, almost half of the anthocyanins were degraded (Lohachoompol, 2007). Similarly, Mejia-Meza et al. (2008) found that blueberries dried in hot air (76 °C) had the lowest retention of polyphenols when compared to freeze-drying and microwave-assisted vacuum drying. For dried fruit intended for direct consumption, osmotic dehydration with concentrated sugar solutions often is applied as a pretreatment to remove water and improve taste (Changrue et al., 2008; Grabowski et al., 2002; Lenart, 1996; Torreggiani, 1993; Torringa et al., 2001). However, leaching of anthocyanins into the liquid medium can be a problem.

One way to decrease drying times is to expose the fruit to rapidly moving air in order to improve heat and mass transfer. In addition, fluidization of the berries can allow the drying air to surround and contact all surfaces. Feng et al. (1999) reported that the drying time of pre-frozen blueberries could be substantially reduced by combining microwave radiation with a spouted fluidized-bed drying system. In addition, the berries were slightly redder and had improved rehydration properties as compared to tray drying. While most fluidized-bed dryers circulate high-velocity air from underneath the product, another approach is used in the JetZone dryer (Kudra & Mujumdar, 2007). In that system, hot air is moved though long tubes that direct the air downward onto an oscillating solid conveyor surface. This creates a bed of air that fluidizes each piece, and the air rises and exits into a cyclone that separates out fine particles. This creates relatively uniform drying, less jet clogging, the ability to create multiple drying zones, and air velocities up to 70 m/s.

Few studies have examined the effects of fluidized-bed drying on the drying time and quality of blueberries. In addition, little is known about the relative phenolic composition and effects of drying on rabbiteye varieties and cultivars. Therefore, the objective of this study was to evaluate the effects of JetZone fluidized bed hot air drying and osmotic dehydration on the moisture properties, anthocyanins, phenolics, antioxidant activity, color, and sensory properties of five rabbiteye blueberry cultivars.

5.2 Materials and Methods

5.2.1 Preparation of Blueberry Samples

Rabbiteye blueberries (*Vaccinium ashei* Reade), machine harvested in South Georgia in 2008, were donated by the Georgia Blueberry Growers Association. Blueberry cultivars included 'Alapaha', 'Tifblue', 'Brightwell', 'Powderblue', and 'Premier'. The 'Brightwell' cultivar was further separated by harvest time: early, mid, and late season harvest. Individually quick-frozen blueberries were stored at -20 °C. Each box of blueberries containing 13.6 kg was divided into three groups to be dried after: no treatment in sugar solution (NT), vacuum tumbled and infused 70 min in sugar (VT) solution, and infused 18 h in sugar without vacuum (NV).

5.2.2 Scarification

Partially thawed blueberries were mechanically scarified by traveling on a moving belt under rotating cogs with serrated blade edges. The blades were set to ~ 5 mm above the belt, allowing the berries to pass under and be slightly compressed and sheared. The blades perforated the skin allowing moisture to diffuse out and sugar to diffuse in during subsequent processing. Scarification was performed on all unsweetened (NT) and NV blueberries. During vacuum tumbling, the scarified blueberries fell apart during the course of multiple rotations. Thus, to

preserve the integrity of the blueberries, vacuum-infused (VT) blueberries were not mechanically scarified.

5.2.3 Osmotic Dehydration

Partially thawed blueberries (4.5 kg) were placed into a Koch Vacuum Tumbler (Model LT-15, Lance Industries, Allentown, WI). Hot (~50 °C) 60 % w/w aqueous sucrose solutions were prepared and added to the blueberries based on 1:1 w/w blueberries to syrup. Vacuum was pulled to 88 kPa. The blueberries were then tumbled at 9 rpm for 35 min, followed by another 35 min after enough sugar was added to return the syrup to 60 °Brix. Samples were briefly washed with fresh cool water and allowed to drain to rinse off excess sugar solution on the outside and thus reduce sugar buildup in the dryer.

For the group infused without vacuum, 4.5 kg of blueberries were placed in the tumbler with the 60 °Brix syrup. The vacuum was not pulled, however, nor was the equipment caused to tumble. The samples remained overnight for ~18 h prior to rinsing and drying.

5.2.4 Hot Air Drying

Drying was carried out in a gas-fired JetZone fluidized bed dryer (Model SNB 1.5x101, Wolverine Proctor & Schwartz, Inc. Merrimac, MA) with one recirculation zone and a smooth, non-perforated, stainless steel hinged, slat-type belt. Based on prior studies, a drying temperature of 107 °C was found to give the best combination of rapid drying and retention of bioactive compounds. The dryer contained a Maxon Corporation OvenPak (Model 405) burner assembly, a 30 HP recirculation fan, and a single 5 HP exhaust fan to remove moist air. Steel mesh cages were used to separate the treatment groups, while allowing sufficient airflow and fluidization of the product. Air velocity was calculated from the pressure drop (ΔP) by:

$$v = \sqrt{\frac{\Delta P}{\rho_a}} \quad (1)$$

where the density of air (r_a) can be calculated by:

$$\rho_a = \frac{(1.293^{kg}/_{m^3})(273K)}{(273K + T)} \quad (2)$$

The calculated air velocity was 38 m/s.

5.2.5 Moisture Content

The moisture content of fresh and dried blueberries was determined using a modified AOAC Method 934.06 (AOAC International, 1995). Five blueberries were cut in half using a razor blade and weighed in pre-dried aluminum weighing dishes (Fisher Scientific). Samples were dried in a Model 1430MS vacuum oven (VWR International, West Chester, PA) at 70 °C and 40 kPa for 24 h, or until a constant mass was achieved. The MC was determined in triplicate per drying batch.

5.2.6 Water activity

For water activity (a_w), three to five blueberries were cut in half and placed in a sample cup. The a_w was determined using an AquaLab Model CX-2 (Decagon Devices Inc, Pullman, WA) at 25 ± 3 °C; a_w measurements were performed in triplicate per drying batch.

5.2.7 Color

Blueberry color was measured using a Chroma Meter (Model CR-410, Konica Minolta, Ramsey, NJ) equipped with a 50 mm aperture and calibrated with a white standard tile. A 325 mL Pyrex dish (3140-100, Corning Inc., Corning, NY) was filled with dried blueberries. Two color measurements were averaged per sample, differing by 180 ° rotation of the sample dish.

5.2.8 Phytochemical Extraction

Both non-dried and dried samples (stored at -80 °C) were lyophilized in a Freezemobile 25 SL Unitop 600L (Virtis Company, Gardiner, NY) at less than 26 Pa. The samples were placed on the heating plates at -45 °C, and vacuum was applied once the internal blueberry temperature reached -40 °C. The plate temperature was increased to 30 °C once the chamber pressure was <7 kPa. Blueberries were dried until the internal berry temperature reached 27 °C. All samples were lyophilized prior to extraction of polyphenolics to eliminate differences in MC between samples and thus variation in the extraction process.

Dried blueberries were ground in a coffee mill (Kitchen Aid, St. Joseph, MI). Blueberry powder and 80 % (v/v) aqueous acetone (1:10 w/v, respectively) were mixed in a 250 mL Erlenmeyer flask, which was loosely covered with aluminum foil and placed in an orbital shaker water bath (Model G76, New Brunswick Scientific, New Brunswick, NJ) at 45 °C for 30 min. After this period, the filtrate was passed through P8 filter paper (Fisher Scientific) into a second Erlenmeyer flask. The recovered sediment was then extracted twice more with 80 % (v/v) aqueous acetone as described above, each time pooling the filtrate. Acetone was removed from the filtrate using a R-210 Büchi Rotovapor (Büchi Corporation, New Castle, DE) at 40 °C; the evaporator was connected to a V-700 vacuum pump and V-850 controller (Büchi) set for 190 mbar. The aqueous residue was transferred to an aluminum dish, frozen and then lyophilized for 24 h to obtain a dry extract. Extracts were scraped and transferred to small vials and then sealed under a nitrogen headspace. Dry extracts were stored in a refrigerator until further analyzed.

5.2.9 Total Monomeric Anthocyanins

The pH-differential method described by Giusti and Wrolstad (2001) was used to determine the total monomeric anthocyanins (TMA) content in the dried blueberry preparations.

Briefly, this method is based on a reversible color change of monomeric anthocyanin pigments with an alteration in the pH; that is, the colored oxonium-ion form exists at pH 1.0, and the colorless hemiketal form predominates at pH 4.5. The difference in absorbance of the pigments at λ = 510 nm is proportional to the anthocyanin concentration; results were expressed as cyanidin-3-*O*-glucoside (C3G) equivalents, as C3G is a common anthocyanin in berries. Two buffer systems were employed in the assay: a 0.025 M potassium chloride buffer, pH 1.0, and a 0.4 M sodium acetate buffer, pH 4.5. Dried blueberry samples were dissolved in pH 1.0 and pH 4.5 buffers from an original concentration of ~1 mg/mL with a dilution factor of 7. After an incubation period of 15 min at room temperature to allow for optimal color development, absorbance readings were taken at λ = 510 and 700 nm with a 8453 UV-visible spectrophotometer (Agilent Technologies, Wilmington, DE). The pH differential absorbance was determined as follows:

$$Abs = (A_{510nm} - A_{700nm})_{@\ pH\ 1.0} - (A_{510nm} - A_{700nm})_{@\ pH\ 4.5} \qquad (1)$$

The TMA content was calculated using the following equation:

$$TMA(mg\ C3G\ eq\ /\ L) = \frac{Abs \times MW \times DF \times 1000}{\varepsilon \times \ell} \qquad (2)$$

where A = absorbance; MW = molecular weight (449.2 g/mol); DF = dilution factor; and ε = molar extinction coefficient (25,740 L cm^{-1} mol^{-1}). For easier comparison to literature values, the TMA content was calculated as mg C3G equivalents per g of extract and per g of dry matter (DM). Conversion to g dry matter (DM) was calculated by multiplying the mg C3G eq. per g

dried extract by an extraction factor, unique to each sample set, which was determined from the g dried extract per g dried blueberry.

5.2.10 Total Phenolics Content

The total phenolics content (TPC) of extracts was determined using the Folin-Ciocalteu reagent as previously described by Singleton et al. (1999) with modifications for a FLUOstar Omega microplate reader (BMG Labtech, Durham, NC). Gallic acid was used as the standard. The absorbance of the samples was measured at 750 nm in a clear polystyrene flat-bottomed 96 well plate (Fisher Scientific, Waltham, MA) with pathlength correction selected. Each sample absorbance was measured in duplicate and averaged with each extract being measured in triplicate. Results were calculated as mg of gallic acid equivalents (GAE) per g of dried blueberry extract and per g DM.

5.2.11 Oxygen Radical Absorbance Capacity

H-ORAC$_{FL}$ of blueberry extracts was determined as described by Prior et al. (2003) with modifications for a FLUOstar Omega microplate reader. Extracts were reconstituted with deionized water, vortexed until particles dispersed, and centrifuged (Centrific Model 228, Fisher Scientific) for 5 min to remove any particulate fines. The assay was carried out in a flat, clear-bottomed 96 well black plate (Costar #3631, Corning, Inc., Corning, NY). Except for the outside wells, each well received either 20 μL of diluted aqueous extract, 20 μL of Trolox (6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid) at concentrations of 6.25, 12.5, 25, 50, and 100 μM, or 40 μL of 75 mM phosphate buffer (pH 7.4) as the blank solution. The microplate reader was programmed to add 400 μL of fluorescein (0.11 μM), followed by 150 μL of 2,2′-azobis(2-amidinopropane) dihydrochloride (AAPH) (31.6 mM, Sigma-Aldrich Chemical Co., St. Louis, MO) to each well. All solutions had been previously incubated at 37 °C. The excitation

wavelength was set at 485 nm. Emission was recorded at 520 nm after the addition of fluorescein and AAPH and every 192 s thereafter, until a 95 % loss of the fluorescence was noted (~ 3 h). Results were calculated based on the fluorescein decay by calculating areas under the curves (AUC) for the phosphate buffer blanks, aqueous blueberry extract samples, and Trolox standards. A standard curve was obtained by plotting the known concentrations of Trolox against the respective AUC for each standard concentration. Final H-ORAC$_{FL}$ values were calculated using the regression equation of the standard curve expressed as μmol Trolox equivalents (TE) per g of extract and per g DM.

5.2.12 Sensory Panels

Experienced Sensory Panel. An experienced panel consisting of ten members evaluated the dried blueberry samples based on a 5-point intensity scale for selected sensory descriptors: color (slightly blue to very blue), degree of shrivel (negligible to intense), sweetness (not sweet to extremely sweet), blueberry flavor intensity (negligible to intense), firmness (soft to very firm), moistness (dry to very moist), grittiness (negligible to very gritty), tooth compaction (negligible to intense), and presence of off-flavors (negligible to intense). The University of Georgia's Institutional Review Board approved all sensory evaluation protocols, advertisements, and handling of research data. Panelists were gathered prior to evaluation and each test attribute was discussed to ensure that all agreed to and understood the definition of each attribute. The evaluation was conducted in a sensory laboratory equipped with individual testing booths having white fluorescent lighting. Panel evaluations were performed in three days. The first day included evaluation of four unsweetened (NT) dried blueberry samples followed by vacuum-infused (VT) samples of the same cultivar. On the second day, panelists evaluated three unsweetened (NT) dried blueberry cultivars followed by the same cultivars vacuum-infused and

then dried. In addition, a commercially sweetened and dried blueberry sample was evaluated as a reference. On the third day, panelists evaluated 18 h infused (NV) dried blueberry cultivars plus the commercially sweetened dried blueberry samples.

Consumer Preference Testing. Consumer preference testing was performed after the experienced panel results were known. Due to the relatively large number of treatment groups, select treatments were pulled from the NT, VT and NV berries for subsequent consumer tests. Three subgroups were used for each, including samples that had low, midrange and high intensity flavor and texture attributes. Preference testing (n = 50 panelists) of the dried blueberries was conducted in three days at the University of Georgia-Athens campus. Consumers were presented three unsweetened (NT) dried blueberry samples with low, medium and high flavor and texture scores among all cultivars. Consumers were asked to taste the samples and rank their preference from most-preferred to least-preferred. The same procedure was performed for the VT and NV dried blueberry samples.

5.2.13 Statistical Analysis

Statistical analysis was performed using SAS 9.1. Mean differences were tested by using a least significant difference (LSD) test ($p \leq 0.05$).

5.3 Results and Discussion

5.3.1 Moisture Properties

Effects of Osmotic Dehydration. Prior to air drying, blueberries were osmotically dehydrated in 60 % sucrose by either vacuum infusion with tumbling (in two 35 min segments) or soaked 18 h in the same solution without vacuum. The water activity, moisture content and °Brix of unsweetened and presweetened blueberries are shown in Table 5.1. Fresh frozen ‘Powderblue’ and ‘Alapaha’ cultivars had the highest initial sugars (15.4 and 16.6 °Brix), while

‘Alapaha’ and mid-season ‘Brightwell’ had the lowest initial moisture (79.4 and 80.3 % wb). Early-season ‘Brightwell’ and ‘Tifblue’ had the lowest average sugar levels (10.9 and 12.0 °Brix). The initial moisture content of the fresh blueberries varied from 79.4 % (‘Alapaha’) to 85.5 % (early ‘Brightwell’). Interestingly, mid-harvest ‘Brightwell’ had a lower moisture content (80.3 %) compared to early ‘Brightwell’ (85.5 %) and late ‘Brightwell’ (83.5 %) blueberries. As expected, the sugar content of ‘Brightwell’ cultivars increased during the season, increasing from 10.9 °Brix for early harvested berries, to 13.0 °Brix for mid-season berries and to 13.9 °Brix for late-harvested berries. It has been reported that total sugars in two *Vaccinium* varieties increased from 35 to 63 % of dry weight during ripening, with the predominant sugars being fructose, glucose and sucrose (Ayaz et al., 2001). Ripe highbush ‘Bluecrop’ blueberries were reported to have sugar levels of 15.1 °Brix (Skrede et al., 2000).

After vacuum infusion with 60 % sucrose, the blueberry moisture content ranged from 75 to 81 %. Grabowski et al. (2007) infused Canadian wild blueberries with sugar to an a_w of 0.89 and moisture levels of 47-54 %. Starting with berries at 84-87 % moisture, they subjected them to a 5:1 syrup to blueberries ratio. Another study infused blueberries in a 30:1 syrup to blueberries mix to avoid dilution of the sugar syrup, and reported a greater moisture loss than solids gain (Nsonzi & Ramaswamy, 1998a). We chose a 1:1 syrup to blueberry ratio to better replicate commercial practices.

Not all cultivars were affected equally by the osmodehydration step, with moisture losses ranging from 1.5 to 11.0 %. ‘Tifblue’ and ‘Premier’ cultivars showed the greatest moisture loss (11.0 and 10.3 %) with a solids uptake of 6 and 8 °Brix (a change of 52 and 76 %). ‘Powderblue’ and ‘Brightwell’ varieties had the least amount of moisture loss at 1.2 and 2.1 %, respectively,

and a solids increase of 1.9 and 8.3 °Brix. There was no correlation between the amount of water lost and the amount of sugars gained by the berries.

Nsonzi and Ramaswamy (1998a) found that the increase in solids during osmodehydration of blueberries was not as great as the moisture loss. In our studies, the °Brix values had a high degree of variability, likely due to differences in diffusion related to berry size, maturity, variations in skin thickness amongst cultivars and number of cracks incurred during the freezing process. Moreira and Sereno (2003) reported that the solute uptake in apple pieces is dominated by diffusion inside the matrix while water loss is controlled by internal diffusion and external flow around the pieces.

Blueberries subject to vacuum infusion for 70 minutes had similar moisture content as those soaked for 18 hours (Table 5.1). The moisture content of NV berries ranged from 78.0 % for 'Alapaha' varieties to 81.9 % for 'Premier'. The sugar levels ranged from 17.6 °Brix for 'Tifblue' to 22.4 °Brix fore late-harvested 'Brightwell' berries. As a group, VT berries had slightly lower moisture contents than NV berries, with a range of 75.0 to 81.4 % for the former, and 78.0 to 81.9 % for the latter. There was no correlation between the final moisture content of VT and NV blueberries. Similarly, the sugar uptake was somewhat greater in the VT berries, with a range of 12.8 to 21.0 °Brix, while the NV berries had a range of 17.6 to 22.4 °Brix. Again, there was no correlation of Brix values in the two groups. It should be recalled that we were unable to both scarify and vacuum-infuse blueberries. Thus, even without scarification, mass transfer of sugars and water was greater during vacuum infusion for 70 min than in scarified berries soaked in syrup for 18 h.

Shi et al. (1995) reported that vacuum increases moisture transfer rates in the osmotic dehydration of apricots, strawberries, and pineapple. In our study, the vacuum was released for

the VT berries after 35 min, the sugar level adjusted back to 60 °Brix, and the vacuum reapplied for an additional 35 min. This is similar to the pulsed vacuum osmotic dehydration (PVOD) method, which has been reported to increase the mass transfer rates by exchanging the internal liquid with external solution via "hydrodynamic mechanisms" (Deng & Zhao, 2008; Fito, 1994; Moreno et al., 2004; Tapia et al., 1999). Thus, PVOD can be used to reduce infusion time. Scarifying the blueberries prior to vacuum infusion, along with increasing syrup solids and quantity, also increases solids uptake (Grabowski et al., 2007; Nsonzi & Ramaswamy, 1998b). PVOD has been used to dehydrate apples (Deng & Zhao, 2008), fruits and vegetables (Fito, 1994; Moreno et al., 2004; Tapia et al., 1999), meat and fish (Collignan et al., 2001).

Changes During JetZone Drying. Blueberries were dried at 107 °C and 38 m/sec in a fluidized bed dryer with specially designed mesh cages to contain the berries. Drying times, moisture content, and a_w for blueberries varying among cultivars, harvest time, and pre-treatment are shown in Table 5.2.

The a_w of <0.60 was desired for the dried blueberries to avoid subsequent microbial growth and give characteristic texture (Barbosa-Canovas & Vega-Mercado, 1996; Changrue et al., 2008). This corresponds to a target moisture content of 15 – 20 % (MacGregor, 2005). Drying times for the blueberries varied from 66 to 99 min with the final a_w varying from 0.605 to 0.327. Moisture contents ranged from 9.1 to 24.1 %, which is consistent with values reported by Grabowski et al. (2007) for dried sweetened blueberries, but not all fit strictly within the 15-20 % target moisture. Unsweetened 'Premier' blueberries had longer drying times than other cultivars (sweetened and unsweetened), needing 99 min to reach a_w=0.558 (18.8 % moisture). Unsweetened 'Alapaha' blueberries had the shortest drying time of 66 min to reach a_w=0.552 (19.8 % moisture). 'Alapaha' were the smallest cultivar, so they were expected to have a shorter

drying time due to a larger surface area to volume ratio (MacGregor, 2005). These results indicated that blueberry cultivar was an important factor in determining drying time.

As a group, VT blueberries dried faster than NT or NV blueberries. Part of this is due to the higher solids content after osmodehydration for VT berries. Grabowski et al. (2002) found that sugar-infused cranberries dried three times faster than untreated cranberries. They noted that the drying rate of infused fruit usually is slower during the initial stages of drying due to the stickiness of the product, but then increases as the fruit becomes fluidized. The shorter drying time of infused as compared to raw cranberries was attributed to the significantly reduced moisture content of the infused cranberries (50 %) compared to 87.4 % in the raw cranberries (Grabowski et al., 2002). In our studies, blueberries were infused to 75 – 81.4 % moisture prior to drying.

Drying times for the VT blueberries ranged from 65 to 95 min, to reach a_w between 0.327 to 0.530. For the NV group, drying times ranged from 71 to 93 min, with a final a_w between 0.489 and 0.605. This generally is much shorter than other methods used to dry whole blueberries. For example, Mejia-Meza et al. (2008) reported drying times of 72 h for freeze-dried blueberries, 4.5 h for a hot air convective dryer and 90 min for a microwave-assisted vacuum dryer. To reach a target of 15 % moisture, Feng et al. (1999) reported drying times of 960 min (tray drying at 70 °C) and 200 min for spouted bed drying. Lohachoompol et al. (2004) dried blueberries in a cabinet drier in several steps for a total time of 5.5 h.

5.3.2 Color

The color of blueberries is an important attribute since it influences quality evaluation (Saftner et al., 2008). The color of blueberries is mainly contributed to red flavylium and blue quinoidal anthocyanins (Mazza & Brouillard, 1987). The color values L*, chroma (c), and hue

(h) of dried blueberries varying by cultivar and pretreatment are presented in Table 5.3. In this system, L* ranges from 0 (black) to 100 (white); thus, a decreased L* value generally denotes darkening. L* varied from 17.51 to 19.71 with the commercially dried blueberry measuring 17.87. L* values were markedly lower, indicating darker samples, than the L*=31-38 for thawed-dried blueberries reported by Feng et al. (1999). L* values were slightly higher for most osmotically dehydrated/dried blueberries, indicating lighter samples compared to the unsweetened/dried blueberries. Osmotic dehydration is known to cause loss in pigmentation, more specifically the anthocyanins responsible for the typical blueberry color (Contreras et al., 2008; Stojanovic & Silva, 2007). However, Stojanovic and Silva (2007) reported no significant change in L*, h, and c values as a result of osmotic concentration of rabbiteye blueberries.

The chroma varied from 2.07 to 3.37 for the dried blueberries with commercially dried blueberries having the lowest chroma value of 1.91. The chroma value can be used to indicate color saturation (Abers & Wrolstad, 1979; Voss, 1992). Chroma values were similar to those reported for thawed and microwave-assisted spouted-bed dried blueberries (Feng et al., 1999). In most cultivars, the chroma value of the overnight-infused dried blueberries was greater than the unsweetened dried blueberries.

Hue has been shown to correlate significantly with visual color perception (Abers & Wrolstad, 1979). McGuire (1992) expressed the hue angles according to color: 0 ° as red, 90 ° as yellow-green, 180 ° as green-blue, and 270 ° as blue-purple. In this study the hue of the dried blueberries ranged from 312.3 ° to 338.1 °, corresponding to the reddish-purple color. VT blueberries had marginally lower hue values 312.3 to 336.2 °) than NV berries (317.1 to 338.1 °), indicating just a slightly more purple hue. Differences in hue angle have been attributed to anthocyanin and phenol composition, content, and interactions with other compounds

(Gonçalves et al., 2007). Hue values were similar to those reported by Feng et al. (1999) for thawed and osmotically dehydrated plus microwave spouted bed dried blueberries.

5.3.3 Anthocyanins and Phenolic Compounds

Total Monomeric Anthocyanins. The total monomeric anthocyanin content (TMA) of rabbiteye blueberry varieties before and after drying is shown in Table 5.4. For fresh blueberries, values ranged from 4.79 to 9.02 mg C3G eq./g extract before treatments (1.45 to 4.76 mg C3G eq./g dry matter). 'Tifblue' exhibited the highest initial TMA of 9.02 C3G eq./g extract followed by 'Alapaha' (7.74 C3G eq./g extract) and mid-season harvested 'Brightwell' (7.40 C3G eq./g extract). On a fresh weight basis, 'Brightwell' blueberries harvested early had 32.4 C3G eq./100 g FW, mid-season had 49.6 mg C3G eq./100g FW, and late season had 39.6 mg C3G eq./100g FW. These values are less than those reported by Prior et al. (1998) for 'Brightwell' blueberries (61.8 mg C3G eq./100g FW). 'Tifblue' blueberries had 84.2 mg C3G eq./100g FW which was comparable to the 87.4 mg C3G eq./100g FW reported by Prior et al. (1998). The anthocyanin content appears to have peaked mid-season in 'Brightwell' (7.40 mg C3G eq./g extract) compared to early- and late-season picked blueberries (5.91 and 4.79 mg C3G eq./g extract, respectively). The concentration of mature blueberries likely has the greatest influence on the anthocyanin content. Connor et al. (2002) reported that the time of harvesting mature 'Elliot' blueberries within a season did not affect the anthocyanin content, total phenolics content, or antioxidant activity. In strawberries, however, da Silva et al. (2007) found that the maturity level, climatic conditions, and post-harvest storage significantly influenced the anthocyanin content within the same cultivar and harvest time.

Grabowski et al. (2007) recommended reusing syrup to reduce anthocyanin loss during osmotic dehydration. For VT berries, we reused syrup by adding the required amount of sugar to

return the Brix to 60 ° following the first vacuum infusion segment. Stojanovic and Silva (2007) reported a 20-60 % reduction in anthocyanins and phenolics after osmotic dehydration for 3 and 12 h. Grabowski et al. (2007) reported 5-15 % loss in anthocyanins in cranberries following osmotic dehydration. While there was no reduction in anthocyanin content after vacuum infusion of 'Premier' blueberries, mid-season harvested 'Brightwell' blueberries lost 22 % of the anthocyanin content following both vacuum infusion and overnight infusion.

Total anthocyanins in dried blueberries ranged from 1.63 to 4.49 mg C3G eq./g extract. Hot air drying of NT blueberries significantly reduced the anthocyanin content by 33-64 %. Similar findings have been reported by others (Kwok et al., 2004; Lohachoompol et al., 2004; Stojanovic & Silva, 2007).

Total Phenolics Content. The total phenolics content (TPC) showed significant variation between the cultivars and treatments (Table 5.4). The TPC of NT blueberries ranged from 22.1 to 39.2 mg GAE/g extract, or on a fresh weight basis 174 mg GAE/100g FW for 'Premier' up to 270.3 mg GAE/100 g FW for 'Tifblue'. 'Brightwell' blueberries had 213.3 to 224.3 mg GAE/100 g FW. In comparison, Prior et al. (1998) reported 361.1 mg GAE/100g FW for 'Brightwell' blueberries. They also reported 271.4 mg GAE/100g FW for 'Tifblue' blueberries, which is comparable to our average of 270.3 mg GAE /100g FW for 'Tifblue'.

Surprisingly, the TPC did not decrease as much as anthocyanin content did with osmotic treatment. VT 'Premier' blueberries had a 55 % reduction in TPC compared to untreated blueberries while the TPC of VT and NV 'Brightwell' blueberries was reduced 15 %. Stojanovic and Silva (2007) reported up to 59 % loss in phenolics of osmotically treated blueberries, and that decreasing the exposure time reduced the loss in phenolic content (Stojanovic & Silva,

2007). Drying substantially increased the phenolic content 45 % in unsweetened late harvested ‘Brightwell’ blueberries and 113 % in unsweetened ‘Premier’ blueberries.

H-ORAC$_{FL}$ Values. The H-ORAC$_{FL}$ values of untreated blueberries varied from 205 to 654 μmol TE/g extract. Accounting for the extraction factor and moisture content of the untreated samples, H-ORAC$_{FL}$ values ranged from 1580 to 3890 μmol TE/100g FW. Values were comparable to Prior et al. (1998) who reported 1530 μmol TE/100g FW for ‘Brightwell’ and 2300 μmol TE/100g FW for ‘Tifblue’ blueberries. On a dry matter basis, values were similar to those reported by Lohachoompol (2007): 140.6 μmol TE/g DM for ‘Powderblue’ and 90.8 μmol TE/g DM for ‘Brightwell’ berries. We found higher values for untreated ‘Powderblue’ blueberries (178 μmol TE/g DM) and ‘Brightwell’ blueberries (96 – 111 μmol TE/g DM). It should be noted that the values reported by Prior et al. (1998) were blueberries grown in Georgia, whereas Lohachoompol (2007) studied blueberries harvested in Australia.

Unlike the results in other studies (Peterson, 2001; Stojanovic & Silva, 2007), hot air drying did not reduce the antioxidant capacity. Drying led to increased H-ORAC$_{FL}$ values for nearly every cultivar when compared on a 100 g fresh weight basis. ‘Premier’ VT blueberries had a lower antioxidant capacity (216 μmol TE/g extract or 2900 μmol TE/100g FW) than NT fresh blueberries (654 μmol TE/g extract or 1560 μmol TE/100g FW). Fresh unsweetened ‘Brightwell’ had an H-ORAC$_{FL}$ value of 2910 μmol TE/100g FW. The antioxidant capacity of the fresh blueberries was reduced 25 % after vacuum tumbling in 60 % sucrose while there was no change in the NV blueberries.

5.3.4 Sensory Analysis

Experienced Panel. Dried blueberries were evaluated for sweetness, blueberry flavor, firmness, moistness, blueness, shrivel, grittiness, and tooth compaction (Table 5.5). Difference

testing noted several differences arising from cultivar or pretreatment. Before infusion treatments, ‘Alapaha’ and ‘Brightwell’ were sweetest and early ‘Brightwell’ was the least sweet. As expected, unsweetened blueberries were less sweet than sugar infused blueberries, with VT berries having the highest sweetness. VT ‘Premier’ and ‘Tifblue’ dried blueberries had the highest rating for sweetness compared to all other drying treatments. These two cultivars also had the lowest Brix values in the syrup remaining after the first infusion step, indicating the greatest uptake in sugar. ‘Tifblue’ and ‘Powderblue’ blueberries had the highest blueberry flavor scores before infusion. ‘Premier’ and ‘Tifblue’ had the highest flavor of the VT blueberries, while ‘Alapaha’ and ‘Tifblue’ had the highest flavor intensity of the NV blueberries. No differences in blueberry flavor intensity were noted as a result of infusion. ‘Tifblue’ blueberries had the highest perceived moistness, while early ‘Brightwell’ had the lowest. VT and NV processes increased perceived moistness. In terms of color, ‘Alapaha’, ‘Premier’ and ‘Powderblue’ were most blue, early ‘Brightwell’ the least. Infusion did not influence perceived color.

‘Alapha’ and early ‘Brightwell’ berries had the highest firmness and ‘Tifblue’ had the lowest. Only ‘Alapaha’ had higher shrivel. Early ‘Brightwell’ had the highest degree of grittiness while ‘Premier’ and ‘Tifblue’ blueberries had the lowest. For tooth compaction, early ‘Brightwell’ was rated highest and ‘Tifblue’ the lowest. VT blueberries also had higher tooth compaction, likely due to stickiness arising from higher sugar levels.

In general, the dried blueberries were slightly grittier and had greater tooth compaction than the commercial sucrose-infused dried blueberries. For some varieties, osmotic dehydration decreased firmness, and for some it increased firmness of the final dried blueberry; but, as a group, infusion was not a significant factor for firmness. Overall, infusion increased the

perceived moistness. A few studies have reported that prior osmotic dehydration improves the texture of dried blueberries by increasing flexibility and reducing toughness (Feng et al., 1999; Kim & Toledo, 1987). One presumption then is that the osmotic pretreatments help improve texture most by increasing perceived moistness.

Consumer Preference Tests. Within each pretreatment category (NT, VT and NV) three cultivars were selected for preference testing, based on results from the experienced panels. One cultivar was selected that had high flavor intensity, blue color and moistness, and low shrivel and grittiness; one that had midrange values; and one that had low values of flavor, color and moistness. Thus, for the unsweetened (NT) group, these were 'Tifblue' (high), 'Powderblue' (median) and early 'Brightwell' (low) cultivars. For the vacuum-infused (VT) group, the selected cultivars were 'Premier' (high), 'Powderblue' (median) and early 'Brightwell' (low). For the passively soaked (NV) group, the cultivars were 'Tifblue' (high), 'Powderblue' (median) and early 'Brightwell' (low). 'Powderblue' berries had the median flavor intensity for all three treatments, while early 'Brightwell' had the lowest scores.

In general, the consumer preference tests concurred with the attribute intensity scores (Table 5.6). Thus, in all pretreatment groups, the cultivar with the lowest attribute score (early 'Brightwell') was the least preferred by consumers. For the unsweetened (NT) blueberries, 'Tifblue' was most preferred, followed by 'Powderblue' and early 'Brightwell'. For VT blueberries, 'Premier' was highest ranked, followed by 'Powderblue' and early 'Brightwell', although differences between 'Premier' and 'Powderblue' were not significant. For the NV blueberries, 'Tifblue' and 'Powderblue' were ranked higher than early 'Brightwell'.

5.4 Conclusions

JetZone fluidized bed drying was a successful means of producing dried rabbiteye blueberries in a relatively short time (70-100 min). Pretreatments, including scarification and infusion, help reduce drying time. Vacuum infusion for 70 min gave similar moisture contents to passive infusion for 24 h. Drying time, color, phytochemical content and sensory scores were also influenced by cultivar. Drying times in the JetZone dryer were influenced both by cultivar and how well that cultivar responded to osmodehydration. While total anthocyanins were reduced by drying, total phenolics and H-ORAC$_{FL}$ values were not. Dried 'Tifblue' was most preferred amongst unsweetened and 24 h infused blueberries. Dried 'Premier' was most preferred among the vacuum-infused blueberries.

References

Abers, J.E. & Wrolstad, R.E., (1979). Causative factors of color deterioration in strawberry preserves during processing and storage. *Journal of Food Science* 44(1), 75-78.

AOAC International, (1995). *Official Methods of Analysis* (16th ed). Association of Official Analytical Chemists International, Arlington, Virginia.

Ayaz, F.A., Kadioglu, A., Bertoft, E., Acar, C. & Turna, I., (2001). Effect of fruit maturation on sugar and organic acid composition in two blueberries (*Vaccinium arctostaphylos* and *V. mytillus*) native to Turkey. *New Zealand Journal of Crop and Horticultural Science* 29(2), 137-141.

Barbosa-Canovas, G.V. & Vega-Mercado, H., (1996). *Dehydration of foods*. Chapman & Hall, New York.

Camire, M.E., Chaovanalikit, A., Dougherty, M.P. & Briggs, J., (2002). Blueberry and grape antocyanins as breakfast cereal colorants. *Journal of Food Science* 67(1), 438-441.

Changrue, V., Orsat, V. & Raghavan, G.S.V., (2008). Osmotically dehydrated microwave-vacuum drying of strawberries. *Journal of Food Processing and Preservation* 32(5), 798-816.

Collignan, A., Bohuon, P., Deumier, F. & Poligne, I., (2001). Osmotic treatment of fish and meat products. *Journal of Food Engineering* 49, 153-162.

Connor, A.M., Luby, J.J., Tong, C.B.S., Finn, C.E. & Hancock, J.F., (2002). Genotypic and environmental variation in antioxidant activity, total phenolic content, and anthocyanin content among blueberry cultivars. *J. Amer. Soc. Hort. Sci.* 127(1), 89-97.

Contreras, C., Martin-Esparza, M.E., Chiralt, A. & Martinez-Navarrete, N., (2008). Influence of microwave application on convective drying: Effects on drying kinetics, and optical and mechanical properties of apple and strawberry. *Journal of Food Engineering* 88(1), 55-64.

da Silva, F.L., Escribano-Bailon, M.T., Alonso, J.J.P., Rivas-Gonzalo, J.C. & Santos-Buelga, C., (2007). Anthocyanin pigments in strawberry. *LWT - Food Science and Technology* 40, 374-382.

Deng, Y. & Zhao, Y.Y., (2008). Effect of pulsed vacuum and ultrasound osmopretreatments on glass transition temperature, texture, microstructure and calcium penetration of dried apples (Fuji). *LWT - Food Science and Technology* 41(9), 1575-1585.

Feng, H., Tang, J.M., Mattinson, D.S. & Fellman, J.K., (1999). Microwave and spouted bed drying of frozen blueberries: The effect of drying and pretreatment methods on physical

properties and retention of flavor volatiles. *Journal of Food Processing and Preservation* 23(6), 463-479.

Fito, P., (1994). Modelling of vacuum osmotic dehydration of food. *Journal of Food Engineering* 22(1-4), 313-328.

Giusti, M.M. & Wrolstad, R.E., (2001). Characterization and measurement of anthocyanins by spectroscopy. Unit F1.2, in: Wrolstad, R.E. (Ed.), *Current Protocols in Food Analytical Chemistry*. John Wiley & Sons, Inc., New York, pp. F1.2.1-F1.2.13.

Gonçalves, B., Silva, A.P., Moutinho-Pereira, J., Bacelar, E., Rosa, E. & Meyer, A.S., (2007). Effect of ripeness and postharvest storage on the evolution of colour and anthocyanins in cherries (*Prunus avium L.*). *Food Chemistry* 103(3), 976-984.

Grabowski, S., Marcotte, M., Poirier, M. & Kudra, T., (2002). Drying characteristics of osmotically pretreated cranberries - Energy and quality aspects. *Drying Technology* 20(10), 1989-2004.

Grabowski, S., Marcotte, M., Quan, D., Taherian, A.R., Zareifard, M.R., Poirier, M. & Kudra, T., (2007). Kinetics and quality aspects of Canadian blueberries and cranberries dried by osmo-connective method. *Drying Technology* 25(2), 367-374.

Kim, M.H. & Toledo, R.T., (1987). Effect of osmotic dyhydration and high temperature fluidized bed drying on properties of dehydrated rabbiteye blueberries. *Journal of Food Science* 52(4), 980-984.

Kong, J.M., Chia, L.S., Goh, N.K., Chia, T.F. & Brouillard, R., (2003). Analysis and biological activities of anthocyanins. *Phytochemistry* 64(5), 923-933.

Kudra, T. & Mujumdar, A.S., (2007). Special drying techniques and novel dryers, in: Mujumdar, A.S. (Ed.), *Handbook of Industrial Drying*, 3rd edition ed. Taylor & Francis, Boca Raton, FL, pp. 453-517.

Kwok, B.H.L., Hu, C., Durance, T. & Kitts, D.D., (2004). Dehydration techniques affect phytochemical contents and free radical scavenging activities of Saskatoon berries (*Amelanchier alnifolia* Nutt.). *Journal of Food Science* 69(3), 122-126.

Lenart, A., (1996). Osmo-convective drying of fruits and vegetables: Technology and application. *Drying Technology* 14(2), 391-413.

Lohachoompol, V., (2007). Effects of drying on anthocyanins in blueberries. *Food Science and Technology, School of Chemical Sciences and Engineering*. The University of New South Wales, Sydney, Australia.

Lohachoompol, V., Srzednicki, G. & Craske, J., (2004). The change of total anthocyanins in blueberries and their antioxidant effect after drying and freezing. *Journal of Biomedicine and Biotechnology* 2004(5), 248-252.

MacGregor, W., (2005). Effects of air velocity, air temperature, and berry diameter on wild blueberry drying. *Drying Technology* 23(1-2), 387-396.

Mazza, G. & Brouillard, R., (1987). Recent developments in the stabilization of anthocyanins in food products. *Food Chemistry* 25(3), 207-225.

McGuire, R.G., (1992). Reporting of objective colour measurements. *Hortscience* 27(12), 1254-1255.

Mejia-Meza, E.I., Yanez, J.A., Davies, N.M., Rasco, B., Younce, F., Remsberg, C.M. & Clary, C., (2008). *Improving nutritional value of dried blueberries (Vaccinium corymbosum L.) combining microwave-vacuum, hot-air drying and freeze drying technologies*. Journal 4(5), article 5. Online: http://www.bepress.com/ijfe/vol4/iss5/art5/

Moreira, R. & Sereno, A.M., (2003). Evaluation of mass transfer coefficients and volumetric shrinkage during osmotic dehydration of apple using sucrose solutions in static and non-static conditions. *Journal of Food Engineering* 57(1), 25-31.

Moreno, J., Bugueno, G., Velasco, V., Petzold, V. & Tabilo-Munizaga, G., (2004). Osmotic dehydration and vacuum impregnation on physicochemical properties of chilean papay (*Carica candamarcensis*). *Journal of Food Science* 69(3), FEP102-FEP106.

Nsonzi, F. & Ramaswamy, H.S., (1998a). Osmotic dehydration kinetics of blueberries. *Drying Technology* 16(3-5), 725-741.

Nsonzi, F. & Ramaswamy, H.S., (1998b). Quality evaluation of osmo-convective dried blueberries. *Drying Technology* 16(3-5), 705-723.

Peterson, D.M., (2001). Oat antioxidants. *Journal of Cereal Science.* 33(2), 115-129.

Prior, R.L., Cao, G.H., Martin, A., Sofic, E., McEwen, J., O'Brien, C., Lischner, N., Ehlenfeldt, M., Kalt, W., Krewer, G. & Mainland, C.M., (1998). Antioxidant capacity as influenced by total phenolic and anthocyanin content, maturity, and variety of Vaccinium species. *Journal of Agricultural and Food Chemistry* 46(7), 2686-2693.

Prior, R.L., Hoang, H., Gu, L.W., Wu, X.L., Bacchiocca, M., Howard, L., Hampsch-Woodill, M., Huang, D.J., Ou, B.X. & Jacob, R., (2003). Assays for hydrophilic and lipophilic antioxidant capacity (oxygen radical absorbance capacity (ORAC(FL))) of plasma and other biological and food samples. *Journal of Agricultural and Food Chemistry* 51(11), 3273-3279.

Saftner, R., Polashock, J., Ehlenfeldt, M. & Vinyard, B., (2008). Instrumental and sensory quality characteristics of blueberry fruit from twelve cultivars. *Postharvest Biology and Technology* 49(1), 19-26.

Shi, X.Q., Fito, P. & Chiralt, A., (1995). Influence of vacuum treatment on mass transfer during osmotic dehydration of fruits. *Food Research International* 28(5), 445-454.

Singleton, V.L., Orthofer, R. & Lamuela-Raventos, R.M., (1999). Analysis of total phenols and other oxidation substrates and antioxidants by means of Folin-Ciocalteu reagent. *Methods in Enzymology* 299, 152-178.

Skrede, G., Wrolstad, R.E. & Durst, R.W., (2000). Changes in anthocyanins and polyphenolics during juice processing of highbush blueberries (*Vaccinium corymbosum* L.). *Journal of Food Science* 65(2), 357-364.

Stojanovic, J. & Silva, J.L., (2007). Influence of osmotic concentration, continuous high frequency ultrasound and dehydration on antioxidants, colour and chemical properties of rabbiteye blueberries. *Food Chemistry* 101(3), 898-906.

Tapia, M.S., Lopez-Malo, A., Consuegra, R., Corte, P. & Welti-Chanes, J., (1999). Minimally processed papaya by vacuum osmotic dehydration (VOD) techniques. *Food Science and Technology International* 5(1), 41-49.

Torreggiani, D., (1993). Osmotic dehydration in fruits and vegetable processing. *Food Research International* 26(2), 59-68.

Torringa, E., Esveld, E., Scheewe, I., Van Den Berg, R. & Bartals, P., (2001). Osmotic dehydration as a pre-treatment before combined microwave-hot-air drying of mushrooms. *Journal of Food Engineering* 49(2-3), 185-191.

Voss, D.H., (1992). Relating colourimeter measurement of plant colour to the royal horticultural society colour chart. *Hortscience* 27(12), 1256-1260.

Zafra-Stone, S., Yasmin, T., Bagchi, M., Chatteriee, A., Vinson, J.A. & Bagchi, D., (2007). Berry anthocyanins as novel antioxidants in human health and disease prevention. *Molecular Nutrition & Food Research* 51(6), 675-683.

Tables

Table 5.1 Water activity (a_w), moisture content (MC), and °Brix values of unsweetened, vacuum infused, and 18 h soaking of rabbiteye blueberries.

Unsweetened (NT)	**a_w**	**MC gH2O 100g**	**°Brix**	**Vacuum Infused (VT)**	**a_w**	**MC gH2O 100g**	**°Brix**	**18 h Soak (NV)**	**a_w**	**MC gH2O 100g**	**°Brix**
Premier	0.986	84.8	11.2	Brightwell early	0.975	81.2	19.2	Premier	0.974	81.9	17.9
Brightwell early	0.985	85.5	10.9	Brightwell late	0.974	81.4	19.4	Tifblue	0.970	79.1	17.6
Tifblue	0.985	84.3	12.0	Alapaha	0.971	78.2	15.9	Alapaha	0.969	78.0	19.6
Brightwell late	0.980	83.5	13.9	Brightwell mid	0.968	78.0	12.8	Brightwell mid	0.969	78.9	19.5
Powderblue	0.978	82.6	15.4	Powderblue	0.967	77.8	17.3	Powderblue	0.967	78.4	18.7
Brightwell mid	0.978	80.3	13.0	Premier	0.966	76.0	21.0	Brightwell early	0.967	78.4	18.7
Alapaha	0.971	79.4	16.6	Tifblue	0.952	75.0	18.3	Brightwell late	0.966	78.1	22.4

Table 5.2 Final water activity (a_w), moisture content (MC), and drying time (min) for fluidized-bed dried rabbiteye blueberries.

Unsweetened (NT)	**a_w**	**MC** gH2O 100g	**Drying Time (min)**	**Vacuum Infused (VT)**	**a_w**	**MC** gH2O 100g	**Drying Time (min)**	**18 h Soak (NV)**	**a_w**	**MC** gH2O 100g	**Drying Time (min)**
Premier	0.558	18.8	99	Premier	0.530	15.7	69	Premier	0.605	24.1	93
Tifblue	0.555	19.9	75	Brightwell early	0.521	27.5	83	Tifblue	0.577	22.1	71
Alapaha	0.552	19.8	66	Alapaha	0.495	14.0	79	Brightwell late	0.569	20.5	76
Powderblue	0.510	16.6	75	Brightwell late	0.456	11.1	65	Powderblue	0.569	19.3	70
Brightwell early	0.491	17.5	77	Powderblue	0.397	12.1	95	Brightwell mid	0.526	17.3	78
Brightwell mid	0.451	15.3	90	Tifblue	0.347	10.5	71	Brightwell early	0.511	18.5	80
Brightwell late	0.378	12.0	74	Brightwell mid	0.327	9.1	83	Alapaha	0.489	16.5	81

Table 5.3 Color values for dried rabbiteye blueberries with varying treatments: unsweetened (NT), vacuum infused (VT), and soaked for 18 h (NV).

Cultivar	Treatment	L*	c	h
Premier	NT	17.90	2.40	329.2
	VT	18.60	2.07	319.9
	NV	18.47	3.17	335.3
Tifblue	NT	18.52	2.52	323.7
	VT	18.43	2.24	321.3
	NV	19.61	2.78	330.1
Powderblue	NT	18.36	2.44	322.5
	VT	19.71	2.58	312.3
	NV	18.81	2.35	317.1
Alapaha	NT	17.87	2.18	325.6
	VT	18.02	2.33	328.6
	NV	18.12	2.36	329.1
Brightwell	NT	18.54	2.74	333.0
early	VT	19.69	3.11	336.2
	NV	18.73	3.37	338.1
Brightwell	NT	19.21	2.33	326.8
mid	VT	19.06	2.32	323.4
	NV	18.62	3.13	336.5
Brightwell	NT	18.32	2.37	325.7
late	VT	18.77	2.40	325.8
	NV	17.51	2.87	332.8
Commercial	Infused	17.87	1.91	315.9

Table 5.4 Total anthocyanin content (TMA), total phenolics content (TPC), and antioxidant capacity (H-ORAC$_{FL}$) of rabbiteye blueberries before and after fluidized-bed drying: (a) values per g of extract; (b) values per g of dry matter. NT-no osmotic pretreatment, VT-vacuum tumbled in 60 % sucrose, NV-soaked 18 h in 60 % sucrose.

(a)

Cultivar	Treatment		TMA (mg C3G eq./ g extract)	TPC (mg GAE/ g extract)	H-ORAC$_{FL}$ (μmol TE/ g extract)
Premier	NT	before	4.99 ± 1.43	39.2 ± 0.5	654 ± 41
		dried	3.32 ± 1.20	42.1 ± 1.9	788 ± 46
	VT	before	5.21 ± 0.05	16.8 ± 2.1	216 ± 27
		dried	1.63 ± 0.49	18.4 ± 1.6	218 ± 25
Tifblue	NT	before	9.02 ± 0.25	32.6 ± 1.3	470 ± 67
		dried	3.21 ± 0.91	39.6 ± 2.7	682 ± 35
Powderblue	NT	before	6.63 ± 0.44	36.1 ± 0.6	537 ± 15
		dried	2.95 ± 0.71	42.8 ± 2.6	706 ± 30
Alapaha	NT	before	7.74 ± 0.36	27.7 ± 1.5	350 ± 24
		dried	2.56 ± 0.08	27.4 ± 0.1	367 ± 9
Brightwell early	NT	before	5.91 ± 0.85	25.5 ± 1.0	348 ± 18
		dried	3.06 ± 0.22	34.2 ± 1.6	461 ± 50
Brightwell mid	NT	before	7.40 ± 0.03	28.6 ± 0.7	390 ± 83
		dried	4.49 ± 0.16	38.7 ± 1.0	597 ± 49
	VT	before	5.78 ± 0.05	22.0 ± 1.5	265 ± 29
		dried	3.08 ± 0.15	33.4 ± 1.4	515 ± 29
	NV	before	5.84 ± 0.13	32.7 ± 3.2	492 ± 62
		dried	1.74 ± 0.06	32.9 ± 2.0	509 ± 82
Brightwell late	NT	before	4.79 ± 0.67	29.1 ± 12.1	205 ± 22
		dried	2.61 ± 0.92	36.0 ± 0.5	583 ± 36

(b)

Cultivar	Treatment		TMA (mg C3G eq./ g DM)	TPC (mg GAE/ g DM)	H-ORAC$_{FL}$ (μmol TE/ g DM)
Premier	NT	before	1.45 ± 0.42	174.0 ± 2.2	2900 ± 180
		dried	1.93 ± 0.69	370.9 ± 16.4	6940 ± 410
	VT	before	2.47 ± 0.03	212.7 ± 26.8	1560 ± 200
		dried	1.28 ± 0.39	388.4 ± 34.2	2610 ± 300
Tifblue	NT	before	4.76 ± 0.13	270.3 ± 10.5	3890 ± 560
		dried	1.93 ± 0.54	373.3 ± 25.7	6430 ± 330
Powderblue	NT	before	2.20 ± 0.14	245.9 ± 3.8	3660 ± 100
		dried	1.15 ± 0.28	343.0 ± 20.8	5660 ± 240
Alapaha	NT	before	2.78 ± 0.13	172.6 ± 9.6	2190 ± 150
		dried	0.80 ± 0.03	148.8 ± 0.7	1990 ± 50
Brightwell early	NT	before	1.83 ± 0.26	114.4 ± 4.3	1560 ± 80
		dried	2.26 ± 0.16	365.9 ± 17.3	4940 ± 540
Brightwell mid	NT	before	2.80 ± 0.01	213.3 ± 5.6	2910 ± 620
		dried	2.28 ± 0.08	387.8 ± 10.1	5980 ± 490
	VT	before	2.42 ± 0.02	208.8 ± 14.2	2190 ± 240
		dried	1.31 ± 0.07	322.2 ± 13.2	4320 ± 240
	NV	before	1.85 ± 0.04	221.9 ± 21.6	3070 ± 390
		dried	1.02 ± 0.04	414.7 ± 25.5	5880 ± 950
Brightwell late	NT	before	2.24 ± 0.31	224.3 ± 93.4	1580 ± 170
		dried	1.44 ± 0.51	326.9 ± 4.9	5300 ± 320

Table 5.5 Experienced panel mean values for descriptors of dried blueberries. NT-no osmotic pretreatment, VT-vacuum tumbled in 60 % sucrose, NV-soaked 18 h in 60 % sucrose.

		Sweetness	Blueberry Flavor	Firmness	Moistness	Blueness	Shrivel	Grittiness	Tooth Compaction
Premier	NT	2.3 ± 1.0	2.6 ± 1.2	3.4 ± 0.9	2.2 ± 0.6	3.9 ± 1.0	3.6 ± 0.9	3.2 ± 1.0	3.0 ± 1.0
	VT	4.3 ± 0.6	3.2 ± 1.3	2.4 ± 0.9	4.1 ± 0.5	4.2 ± 1.0	3.1 ± 0.9	1.9 ± 0.8	3.3 ± 1.4
	NV	2.2 ± 1.0	3.0 ± 1.0	2.9 ± 0.5	2.6 ± 0.9	3.1 ± 1.4	3.3 ± 0.9	3.0 ± 0.8	2.6 ± 0.9
Tifblue	NT	2.0 ± 1.1	3.2 ± 1.0	3.4 ± 1.0	2.3 ± 0.9	3.6 ± 0.9	3.3 ± 1.1	3.0 ± 1.2	2.7 ± 0.8
	VT	3.8 ± 0.9	3.0 ± 1.1	2.8 ± 1.0	3.5 ± 0.8	3.5 ± 0.9	3.6 ± 0.8	1.7 ± 0.6	3.1 ± 1.4
	NV	3.0 ± 1.4	3.3 ± 0.8	2.1 ± 0.5	3.5 ± 0.5	3.0 ± 1.2	3.4 ± 0.8	2.3 ± 0.9	1.6 ± 0.5
Powderblue	NT	2.1 ± 0.8	3.0 ± 1.1	3.5 ± 0.5	2.0 ± 0.8	3.7 ± 1.2	3.2 ± 0.4	3.5 ± 0.5	3.0 ± 0.9
	VT	2.4 ± 1.0	2.6 ± 1.0	3.9 ± 0.9	2.0 ± 0.4	3.3 ± 0.9	3.2 ± 0.9	3.3 ± 1.0	3.5 ± 1.3
	NV	2.4 ± 0.9	2.9 ± 0.8	2.4 ± 1.0	3.1 ± 0.7	4.0 ± 0.9	3.5 ± 1.3	3.6 ± 0.7	2.5 ± 1.1
Alapaha	NT	2.5 ± 1.4	2.2 ± 1.0	3.5 ± 0.9	2.1 ± 0.7	3.8 ± 1.3	3.8 ± 0.9	3.3 ± 0.8	2.8 ± 1.1
	VT	2.8 ± 1.0	2.9 ± 1.0	4.1 ± 0.8	1.9 ± 0.5	3.5 ± 1.2	4.1 ± 0.8	3.6 ± 0.7	3.5 ± 1.1
	NV	3.4 ± 0.8	3.5 ± 1.2	3.4 ± 0.8	2.9 ± 0.6	4.0 ± 1.2	3.7 ± 0.9	2.9 ± 0.8	3.0 ± 1.0
Brightwell early	NT	1.5 ± 0.5	2.0 ± 0.9	3.7 ± 1.0	1.5 ± 0.5	3.5 ± 1.0	3.1 ± 1.1	4.0 ± 1.2	2.9 ± 1.3
	VT	1.6 ± 0.8	1.7 ± 0.9	3.5 ± 1.0	1.6 ± 0.8	2.8 ± 1.5	3.5 ± 1.1	4.0 ± 0.8	3.4 ± 1.1
	NV	1.7 ± 0.9	2.1 ± 1.0	3.7 ± 0.8	1.4 ± 0.5	2.6 ± 1.4	3.4 ± 1.2	4.2 ± 0.8	3.4 ± 1.1
Brightwell mid	NT	2.3 ± 0.8	2.9 ± 0.9	3.5 ± 0.7	1.7 ± 0.6	3.5 ± 1.0	3.3 ± 0.8	3.5 ± 0.8	3.1 ± 1.0
	VT	2.3 ± 0.8	2.7 ± 1.1	3.6 ± 0.8	2.1 ± 0.5	3.9 ± 1.1	3.7 ± 0.9	3.4 ± 1.4	3.3 ± 0.9
	NV	2.0 ± 0.8	2.1 ± 0.9	3.3 ± 0.6	1.8 ± 0.6	3.4 ± 1.4	3.3 ± 1.0	3.8 ± 0.9	3.1 ± 1.1
Brightwell late	NT	2.4 ± 1.0	2.3 ± 0.6	3.6 ± 0.9	1.4 ± 0.5	3.6 ± 1.0	3.3 ± 0.8	4.3 ± 0.8	3.1 ± 0.8
	VT	3.2 ± 1.0	2.8 ± 0.9	3.9 ± 0.5	2.5 ± 0.7	3.9 ± 1.0	3.8 ± 0.9	2.9 ± 0.9	3.6 ± 1.0
	NV	2.4 ± 0.7	2.2 ± 1.0	3.1 ± 0.6	2.4 ± 0.7	3.0 ± 1.2	3.8 ± 1.0	3.8 ± 1.0	2.9 ± 1.2
Commercial	inf	3.6 ± 1.0	3.3 ± 1.3	2.1 ± 0.7	4.5 ± 0.7	4.3 ± 1.4	3.4 ± 0.9	1.6 ± 0.7	2.2 ± 1.5
	inf	3.5 ± 0.5	3.8 ± 1.2	2.2 ± 0.9	4.3 ± 0.8	4.2 ± 1.3	3.0 ± 1.0	1.6 ± 0.7	2.0 ± 0.9

Table 5.6 Preference test rankings for blueberry samples selected based on experienced panel descriptor values. Values in a column followed by a different superscript indicate significant difference ($p<0.05$) between ranking samples.

	NT Blueberries	Rank Total	VT Blueberries	Rank Total	NV Blueberries	Rank Total
High	Tifblue	71[a]	Premier	76[a]	Tifblue	71[a]
Medium	Powderblue	99[b]	Powderblue	91[a]	Powderblue	90[a]
Low	Brightwell early	130[c]	Brightwell early	139[b]	Brightwell early	151[b]

CHAPTER 6

CONCLUSIONS

Vacuum belt drying is a continuous drying method that can produce dried blueberries (a_w < 0.5) in less than 2 h. Pretreatments before drying can be implemented to reduce drying time. Mechanical skin abrasion can decrease the drying time of larger fresh blueberries, and a range of intermediate and low moisture fruit can be achieved by varying the drying time and temperatures. Placing frozen blueberries into the dryer resulted in shorter drying times, less pigment bleeding from the surface, and better structure retention likely due to cracks forming throughout the epidermal and waxy cuticle layers, which create more areas for moisture migration. Also, vacuum belt drying may be a possible alternative to freeze-drying due to its continuous process and ability to maintain, if not increase, the antioxidant capacity of dried blueberries.

Additional statistical analysis could be performed on both data sets (fresh and frozen) of vacuum belt dried blueberries. Including vacuum as a covariant could yield deeper insight into understanding and optimizing the process variables of vacuum belt drying. The data sets could be analyzed as multivariant between the moisture content and water activity values. Contrast statements and estimates at each level for RT, CT, time, size, and abrasion can be performed to identify potential significant relationships not uncovered by the split-split plot analysis. Drying of other varieties of blueberries is recommended as attributes between cultivars differ dramatically as found in Chapter 5.

The JetZone fluidized bed dryer successfully dehydrated both sugar-infused and non-infused blueberries to a_w less than 0.55 in less than 2 h. Pulsed vacuum infusion shows promise for decreasing processing time compared to passive, atmospheric sugar infusion. Drying at 107 °C resulted in the shortest drying time while maintaining blueberry flavor and high consumer preference. Sugar-infusion and higher dryer temperatures reduced the total monomeric anthocyanin content compared to fresh blueberries. Total phenolics content increased with drying, while oxygen radical scavenging ability both increased and decreased compared to fresh fruit depending upon drying temperature. Mechanical pretreatment piercing the protective epidermal layer of the blueberry skin combined with sugar infusion work well to decrease drying time. Drying time, color, phytochemical content and sensory scores varied significantly between rabbiteye cultivars. Dried 'Tifblue' was most preferred amongst unsweetened and 24 h infused blueberries. Dried 'Premier' was most preferred among the vacuum-infused blueberries.

Further development of the drying conditions for both vacuum belt drying and JetZone fluidized bed drying are suggested with particular consideration of the blueberry cultivar and mechanical pretreatment. It would interesting to determine the drying conditions required to achieve a water activity of 0.60 for each blueberry cultivar and reassess the sensory attributes for each blueberry. All blueberry cultivars studied have the potential to become excellent dried products. The drying methods studied show promise for maintaining the bioactive compounds while achieving high quality dried blueberries in shorter time periods than traditional hot air drying and freeze-drying.

APPENDIX A

SPLIT-SPLIT PLOT SAS 9.1 PROGRAM AND OUTPUT FOR WATER ACTIVITY OF FRESH BLUEBERRIES VACUUM BELT DRIED

A lot of work went into the development of the split-split plot design and writing of the SAS program. Fresh blueberries, separated into two sizes ('large' and 'small'), were pretreated by mechanical abrasion (abraded) or were the control (non-abraded) and were vacuum belt dried at six temperature combinations (two radiation temperatures of 100 °C and 120 °C combined with three conduction temperatures of 90 °C, 110 °C, and 130 °C) for three time periods (90, 105, and 120 min). The increments between the temperatures (20 °C) and time (15 min) were purposeful to allow testing for Linear and Quadratic trends, requiring increments to be the same between the levels. The design was split by time (quantitative factor) and radiation temperature (qualitative factor). The first split, time, was due to the vacuum belt dryer being capable of running for only one drying time period with all samples removed at the same time. The second split, radiation temperature, was because the dryer had only one radiation heating plate expanding over the three conduction heating plates. Thus, for each drying run, either 100 °C or 120 °C was set for the radiation heat plate. Radiation temperature was qualitative because of having only two levels while time and conduction temperature were quantitative due to having three levels. Moisture content and water activity were measured for each dried sample combination of blueberries and analyzed in the split-split plot SAS program to determine the effects of drying time, conduction temperature, radiation temperature, abrasion, and berry size on the moisture content and water activity (with each replication being randomly allocated to the

split-split plot design). The program was written to consider either water activity or moisture content; therefore the outputs are similar to each other. To analyze the moisture content, replace water activity (aw) with moisture content and corresponding data. The following program and output were used to create the ANOVA table for the water activity values of refrigerated fresh blueberries.

PROGRAM

```
/* Split-Split Plot Design... */

dm 'output; clear; log; clear';
options ls=72 ps=55 pageno=1 formdlim=' ';
title 'Split-Split Plot Statistical Analysis of Fresh Blueberry Final Aw';
title1 'Batch Vacuum-belt Drying Analysis 23 May 2010';
data one;
do time=1 to 3;
        do RT=1 to 2;
                do CT=1 to 3;
                        do size=1 to 2;
                                do abrade=1 to 2;
                                        do rep=1 to 9;

input aw@@;
output;
end;end;end;end;end;end;

cards;
0.937 0.904 0.918 0.934 0.933 0.946 0.951 0.814  0.895
0.928  0.957 0.867 0.829 0.902 0.911 0.885 0.88 0.838
0.952 0.939 0.955 0.949 0.951 0.949 0.948 0.922 0.939
0.959 0.965 0.949 0.776 0.844 0.922 0.856 0.833 0.757
0.942 0.848 0.931 0.915 0.898 0.914 0.361 0.491 0.509
0.643 0.853 0.824 0.769 0.634 0.711 0.904 0.867 0.87
0.783 0.771 0.469 0.889 0.933 0.922 0.765 0.85 0.826
0.79 0.78 0.607 0.896 0.379 0.785 0.636 0.73 0.617
0.494 0.598 0.726 0.818 0.492 0.806 0.702 0.815 0.854
0.358 0.363 0.346 0.461 0.311 0.31 0.312 0.339 0.282
0.823 0.84 0.615 0.601 0.737 0.588 0.738 0.702 0.685
0.327 0.671 0.709 0.778 0.841 0.779 0.296 0.337 0.303
0.927 0.817 0.858 0.95 0.829 0.829  0.746 0.843 0.663
0.92 0.907 0.789 0.879 0.847 0.934 0.943 0.916 0.895
0.915 0.955 0.945 0.899 0.93 0.942 0.819 0.935 0.917
0.811 0.872 0.886 0.874 0.83 0.539 0.802 0.802 0.802
0.897 0.725 0.734 0.363 0.536 0.317 0.313 0.325 0.401
0.908 0.863 0.82 0.836 0.606 0.684 0.286 0.543 0.302
0.895 0.855 0.847 0.796 0.875 0.741 0.555 0.445 0.616
0.405 0.745 0.784 0.592 0.704 0.429 0.610 0.610 0.610
0.292 0.35 0.356 0.721 0.299 0.288 0.303 0.282 0.256
0.294 0.331 0.27 0.455 0.589 0.435 0.353 0.336 0.336
0.637 0.571 0.431 0.299 0.356 0.357 0.442 0.442 0.442
0.747 0.742 0.422 0.521 0.485 0.535 0.212 0.263 0.277
```

```
0.914 0.89 0.908 0.863 0.932 0.858 0.736 0.888 0.484
0.935 0.917 0.895 0.961 0.928 0.916 0.962 0.927 0.931
0.878 0.968 0.912 0.866 0.877 0.711 0.923 0.943 0.921
0.703 0.842 0.824 0.692 0.882 0.725 0.595 0.823 0.753
0.352 0.673 0.474 0.713 0.415 0.291 0.868 0.819 0.791
0.49 0.821 0.754 0.299 0.821 0.384 0.333 0.381 0.336
0.618 0.61 0.857 0.69 0.731 0.711 0.606 0.337 0.652
0.74 0.861 0.763 0.292 0.531 0.742 0.329 0.427 0.451
0.35 0.403 0.269 0.313 0.471 0.283 0.334 0.35 0.35
0.296 0.297 0.323 0.777 0.684 0.418 0.351 0.359 0.365
0.297 0.327 0.306 0.294 0.294 0.291 0.443 0.345 0.333
0.323 0.332 0.326 0.29 0.275 0.293 0.282 0.334 0.295
0.813 0.945 0.802 0.717 0.749 0.783 0.425 0.702 0.684
0.809 0.712 0.893 0.814 0.807 0.907 0.823 0.562 0.737
0.929 0.795 0.738 0.606 0.781 0.756 0.727 0.583 0.467
0.901 0.789 0.707 0.848 0.688 0.914 0.885 0.901 0.904
0.627 0.703 0.904 0.307 0.35 0.306 0.282 0.421 0.269
0.496 0.357 0.618 0.284 0.322 0.317 0.325 0.335 0.345
0.398 0.299 0.335 0.613 0.672 0.414 0.272 0.294 0.285
0.516 0.414 0.309 0.384 0.726 0.301 0.315 0.31 0.333
0.46 0.312 0.291 0.294 0.366 0.318 0.294 0.296 0.327
0.306 0.348 0.37 0.273 0.279 0.289 0.273 0.397 0.369
0.359 0.413 0.447 0.345 0.304 0.304 0.288 0.265 0.445
0.291 0.306 0.336 0.628 0.714 0.76 0.3 0.353 0.382
0.707 0.725 0.578 0.878 0.856 0.855 0.661 0.902 0.538
0.785 0.737 0.919 0.433 0.384 0.366 0.48 0.297 0.531
0.931 0.908 0.942 0.919 0.867 0.922 0.768 0.477 0.338
0.953 0.813 0.866 0.357 0.832 0.912 0.926 0.941 0.953
0.766 0.796 0.865 0.264 0.356 0.378 0.571 0.571 0.571
0.362 0.303 0.317 0.355 0.303 0.626 0.293 0.294 0.32
0.674 0.293 0.882 0.512 0.722 0.716 0.362 0.386 0.293
0.336 0.361 0.421 0.508 0.434 0.642 0.279 0.368 0.285
0.39 0.27 0.406 0.269 0.294 0.287 0.288 0.286 0.27
0.355 0.381 0.412 0.326 0.306 0.291 0.3 0.292 0.285
0.32 0.336 0.336 0.272 0.375 0.323 0.268 0.305 0.399
0.244 0.276 0.259 0.32 0.295 0.309 0.282 0.28 0.312
0.767 0.761 0.871 0.746 0.774 0.719 0.259 0.293 0.334
0.494 0.691 0.792 0.266 0.345 0.575 0.374 0.313 0.621
0.842 0.888 0.873 0.816 0.357 0.617 0.452 0.381 0.53
0.286 0.286 0.296 0.347 0.297 0.312 0.356 0.334 0.34
0.501 0.562 0.322 0.268 0.307 0.316 0.32 0.331 0.269
0.408 0.304 0.34 0.751 0.466 0.326 0.352 0.333 0.368
0.373 0.405 0.377 0.302 0.302 0.291 0.292 0.55 0.42
0.268 0.271 0.257 0.465 0.36 0.631 0.337 0.305 0.285
0.266 0.276 0.283 0.304 0.314 0.294 0.369 0.284 0.338
0.307 0.327 0.297 0.346 0.378 0.377 0.333 0.294 0.301
0.494 0.691 0.792 0.64 0.462 0.698 0.322 0.281 0.272
0.341 0.296 0.341 0.332 0.316 0.444 0.308 0.288 0.297
;
/*proc print; run; /*Yes*/
proc glm data=one outstat=junk1;
class rep abrade size CT RT time;
model aw=time|RT|CT|size|abrade|rep /ss3;
means time RT CT size abrade;
run;
```

```
data two;
set junk1;
keep _SOURCE_ DF SS;
output;
proc print data=two;
/*This creates data set named two using the proc glm output saved as junk1 but keeping only the source, df, and SS
*/
title 'RT qual, Time quantitative; SOURCE, DF & SS data only....contrasts';
run;

/*To find Error a/b/c SS and DFs */
data two2; set two;
proc iml;
use two2;
read all var {DF SS} into P;
ER=J(3,2,0);
/*Error terms matrix, col1=df, col2=SS; row1-2-3=Error(a)-(b)-(c) */
ER[1,1]=P[34,1]; ER[1,2]=P[34,2]; /*The df for Error(a) correspond to row 34 column 1 and SS for Error (a)
corresponds to row 34 column 2 which is found by looking at the output from the proc print data=two */
ER[2,1]=P[35,1]+P[36,1]; ER[2,2]=P[35,2]+P[36,2];
EC=J(28,2,0); /*To collect all 28 rep*effects for Error(c) */
EC[1:28,1:2]=P[37:64,1:2];
ER[3,1]=EC[+,1]; ER[3,2]=EC[+,2]; /*sum over rows of EC */
print ER EC; /*OK*/
varnames={DF SS};
create outER from ER (|colname=varnames|);
append from ER;
run;

data ER; set outER;          /*This ER dataset has ErrorSSa/b/c */
if _N_ = 1 then _SOURCE_ = 'ERRORA';
if _N_ = 2 then _SOURCE_ = 'ERRORB';
if _N_ = 3 then _SOURCE_ = 'ERRORC';
output; run;
data two2;
set two ER;
proc print data=two2;
title "Is this two2"; run; /*OK*/

/*WHOLE PLOTS part which includes time, rep, Linear Time, and Quad Time with error term, Error(a), being
time*rep */
proc glm data=one outstat=junk1;
title1 "Whole Plot pieces: Time and reps";
class time rep;
model aw=time|rep /ss3;
contrast 'Linear Time' time -1 0 1;
contrast 'Quad Time' time -1 2 -1;
test h=time e=time*rep;
test h=rep e=time*rep;
run;

proc print data=junk1;
title2 "Do we have <junk1>"; run; /*Yes*/

data whole;
set junk1 end=last;
```

```
keep _SOURCE_ DF SS;
title2 "Time contrasts";
retain div dfE LinT QuadT 0;
if _N_ = 4 then dfE=DF; else dfE=dfE+0;      /*This is Error(a) */
if _N_ = 4 then div=SS/DF; else div=div+0;
if _N_ = 5 then LinT=SS; else LinT=LinT+0;
if _N_ = 6 then QuadT=SS; else QuadT=QuadT+0;
if last then do;
  /*to find F and p-values for Lin/Quad Time */
  LinTMS=LinT; QuadTMS=QuadT; /* df=1 here */
  FLinT=LinTMS/div; pLinT=1-probf(FLinT,1,dfE);
  FQuadT=QuadTMS/div; pQuadT=1-probf(FQuadT,1,dfE);
  file print;
  put ///'     (LinearTime)SS = ' LinT;
  put / '      (LinearTime)MS = ' LinTMS;
  put /'      F(LinT) = ' FLinT 'p-value = ' pLinT;
  put ///'     (QuadTime)SS = ' QuadT;
  put / '      (QuadTime)MS = ' QuadTMS;
  put /'      F(QuadT) = ' FQuadT 'p-value = ' pQuadT;
  output;
end;
run;

/*SPLIT-PLOT part */
proc glm data=one outstat=junk2;
title1 "Split plot pieces: RT, RTxTime";
class RT time;
model aw=RT|time/ss3;
contrast "Linear Time" time -1 0 1;
contrast "LinTime@RT1" time -1 0 1 RT*time -1 0 1;
contrast "LinTime@RT2" time -1 0 1 RT*time 0 0 0 -1 0 1;
run;

/*proc print data=junk2;
title "Do we have <junk2>"; run; /*Yes*/

/*Find RT x Linear Time Contrast*/
data split1;
set ER junk2;  /*merge Error a/b/c dataset with junk2 */
keep _SOURCE_ DF SS;
proc print;
title2 "Do we have <split1>"; run; /*Yes*/
run;
title2 ' ';
data split1; set split1 end=last;
title1 "Split Plot pieces: RT, RT*Time and Linear contrasts";
retain div dfE dfRT dfRTtime RT RTtime RTLinT 0;
if _N_ = 2 then dfE=DF; else dfE=dfE+0;      /*This is Error(b) */
if _N_ = 2 then div=SS/DF; else div=div+0;
if _N_ = 5 then dfRT=DF; else dfRT=dfRT+0;  /*df for RTxLinTime*/
if _N_ = 7 then dfRTtime=DF; else dfRTtime=dfRTtime+0; /*df for RTxTime */
if _N_ = 5 then RT=SS; else RT=RT+0; /* RT SS */
if _N_ = 7 then RTtime=SS; else RTtime=RTtime+0; /*RTxTime SS */
if _N_ < 8 then SS=0;
else if _N_ = 8 then SS=-SS;
RTLinT=RTLinT+SS;  /* RtxLinTime SS */
```

```
if last then do;
  /*to find F and p-values for RT, RTxTime, RTxLinTime */
  RTMS=RT/dfRT;    /* RT MS */
  FRT=RTMS/div; pRT=1-probf(FRT,dfRT,dfE); /* RT F-, p- values*/
  RTtimeMS=RTtime/dfRTtime;
  FRTtime=RTtimeMS/div; pRTtime=1-probf(FRTtime,dfRTtime,dfE);
  RTLinTMS=RTLinT/dfRT;
  FRTLinT=RTLinTMS/div; pRTLinT=1-probf(FRTLinT,dfRT,dfE);
  file print;
  put ///'     (RT)SS = ' RT;
  put / '      (RT)MS = ' RTMS;
  put /'      F(RT) = ' FRT 'p-value = ' pRT;
  put ///'     (RTxTime)SS = ' RTtime;
  put / '      (RTxTime)MS = ' RTtimeMS;
  put /'      F(RTxTime) = ' FRTtime 'p-value = ' pRTtime;
  put ///'     (RT x LinearTime)SS = ' RTLinT;
  put / '      (RT x LinearTime)MS = ' RTLinTMS;
  put /'      F(RT x LinT) = ' FRTLinT 'p-value = ' pRTLinT;
  output;
end;
run;
/*Do RT x Quad Time contrast*/
proc glm data=one outstat=junk22;
title1 "Split Plot pieces: RT by Quad Time contrasts";
class RT time;
model aw=RT|time/ss3;
contrast "Quad Time" time -1 2 -1;
contrast "QuadTime@RT1" time -1 2 -1 RT*time -1 2 -1;
contrast "QuadTime@RT2" time -1 2 -1 RT*time 0 0 0 -1 2 -1;
run;

/*proc print data=junk22;
title2 "Do we have <junk22>"; run; /*Yes*/

/*Find RT x Quad Time Contrast*/
data split2;
set ER junk22;  /*merge Error a/b/c dataset with junk22 */
keep _SOURCE_ DF SS;
proc print;
title2 "Do we have <split2>"; run; /*Yes*/
run; title2 ' ';
data split2; set split2 end=last;
title1 "Split Plot pieces: RT by Quad Time contrast";
retain div dfE dfRT RTQuadT 0;
if _N_ = 2 then dfE=DF; else dfE=dfE+0;      /*This is Error(b) */
if _N_ = 2 then div=SS/DF; else div=div+0;
if _N_ = 5 then dfRT=DF; else dfRT=dfRT+0;  /*df for RTxQuadTime*/
if _N_ < 8 then SS=0;
else if _N_ = 8 then SS=-SS;
RTQuadT=RTQuadT+SS;
if last then do;
  /*to find F and p-values for RTxQuadTime */
  RTQuadTMS=RTQuadT/dfRT;
  FRTQuadT=RTQuadTMS/div; pRTQuadT=1-probf(FRTQuadT,dfRT,dfE);
  file print;
  put ///'     (RT x QuadTime)SS = ' RTQuadT;
```

```
 put / '     (RT x QuadTime)MS = ' RTQuadTMS;
 put /'     F(RT x QuadT) = ' FRTQuadT 'p-value = ' pRTQuadT;
 output;
end;
run;

/* SPLIT-SPLIT-PLOT part (Will do this in pieces, to try to avoid mistakes in using the outstat datasets-pull
together results at end */
proc glm data=one outstat=junk3;
title1 "Split-Split pieces: CT, and CT contrasts";
class CT;
model aw=CT/ss3;
contrast "Linear CT" CT -1 0 1;
contrast "Quad CT" CT -1 2 -1;
run;
proc print data=junk3;
title2 "Do we have <junk3>"; run; /*Yes*/

data splitsplit;
set ER junk3; /*merge Error a/b/c dataset with junk3 */
keep _SOURCE_ DF SS;
proc print;
title2 "Do we have <splitsplit>"; run; /*Yes*/
run; title2 ' ';
data splitsplit; set splitsplit end=last;
title1 "Split-Split pieces: CT, and CT contrasts";
retain div dfE dfCT CT LinCT QuadCT 0;
if _N_ = 3 then dfE=DF; else dfE=dfE+0;      /*This is Error(c) */
if _N_ = 3 then div=SS/DF; else div=div+0;
if _N_ = 5 then dfCT=DF; else dfCT=dfCT+0;   /*CT df */
if _N_ = 5 then CT = SS; else CT=CT+0;  /* CT SS */
if _N_ = 6 then LinCT=SS; else LinCT=LinCT+0;
if _N_ = 7 then QuadCT=SS; else QuadCT=QuadCT+0;
if last then do;
 /*to find F and p-values for CT, Lin/Quad CT */
 CTMS=CT/dfCT;
 FCT=CTMS/div; pCT=1-probf(FCT,dfCT,dfE);
 LinCTMS=LinCT; QuadCTMS=QuadCT; /* df=1 here */
 FLinCT=LinCTMS/div; pLinCT=1-probf(FLinCT,1,dfE);
 FQuadCT=QuadCTMS/div; pQuadCT=1-probf(FQuadCT,1,dfE);
 file print;
 put ///'    (CT)SS = ' CT;
 put / '     (CT)MS = ' CTMS;
 put /'     F(CT) = ' FCT 'p-value = ' pCT;
 put ///'    (Linear CT)SS = ' LinCT;
 put / '     (Linear CT)MS = ' LinCTMS;
 put /'     F(LinCT) = ' FLinCT 'p-value = ' pLinCT;
 put ///'    (Quad CT)SS = ' QuadCT;
 put / '     (Quad CT)MS = ' QuadCTMS;
 put /'     F(Quad CT) = ' FQuadCT 'p-value = ' pQuadCT;
 output;
end;
run;

/* CT x Time contrasts */
proc glm data=one outstat=junk32;
```

```
title1 "Split-Split pieces: CT x Time contrasts";
class CT time;
model aw=CT|time /ss3;
contrast "LinCTxLinTime" CT*time 1 0 -1 0 0 0 -1 0 1;
contrast "LinCTxQuadTime" CT*time 1 -2 1 0 0 0 -1 2 -1;
contrast "QuadCTxLinTime" CT*time 1 0 -1 -2 0 2 1 0 -1;
contrast "QuadCTxQuadTime" CT*time 1 -2 1 -2 4 -2 1 -2 1;
run;
proc print data=junk32;
title2 "Do we have <junk32>"; run; /*Yes*/

data splitsplit2;
set ER junk32; /*merge Error a/b/c dataset with junk32 */
keep _SOURCE_ DF SS;
proc print;
title2 "Do we have <splitsplit2>"; run; /*Yes*/
run; title2 ' ';
data splitsplit2; set splitsplit2 end=last;
title "Split-Split pieces: CT, CT x Time contrasts";
retain div dfE dfCTtime CTtime C1 C2 C3 C4 0;
          /*C1==LinCTLinT,C2=LinCTQuadT,C3=QuadCTLinT,C4=QuadCTQuadT*/
if _N_ = 3 then dfE=DF; else dfE=dfE+0;      /*This is Error(c) */
if _N_ = 3 then div=SS/DF; else div=div+0;
if _N_ = 7 then dfCTtime=DF; else dfCTtime=dfCTtime+0; /* df CTxTime */
if _N_ = 7 then CTtime=SS; else CTtime=CTtime+0;   /* CTxTime SS */
if _N_ = 8 then C1=SS; else C1=C1+0;
if _N_ = 9 then C2=SS; else C2=C2+0;
if _N_ = 10 then C3=SS; else C3=C3+0;
if _N_ = 11 then C4=SS; else C4=C4+0;
if last then do;
 /*to find F and p-values CT x Time and components */
 CTtimeMS=CTtime/dfCTtime;
 FCTtime=CTtimeMS/div; pCTtime=1-probf(FCTtime,dfCTtime,dfE);
 C1MS=C1; C2MS=C2;C3MS=C3;C4MS=C4; /* df=1 here */
 FC1=C1MS/div; pC1=1-probf(FC1,1,dfE);
 FC2=C2MS/div; pC2=1-probf(FC2,1,dfE);
 FC3=C3MS/div; pC3=1-probf(FC3,1,dfE);
 FC4=C4MS/div; pC4=1-probf(FC4,1,dfE);
 file print;
 put ///'    (CT x Time)SS = ' CTtime;
 put / '     (CT x Time)MS = ' CTtimeMS;
 put /'     F(CT x Time) = ' FCTtime 'p-value = ' pCTtime;
 put ///'    (LinearCT x LinearTime)SS = ' C1;
 put / '     (LinearCT x LinearTime)MS = ' C1MS;
 put /'     F(LinCT x LinTime) = ' FC1 'p-value = ' pC1;
 put ///'    (LinearCT x Quadratic Time)SS = ' C2;
 put / '     (LinearCT x Quadratic Time)MS = ' C2MS;
 put /'     F(LinCT x QuadTime) = ' FC2 'p-value = ' pC2;
 put ///'    (QuadraticCT x LinearTime)SS = ' C3;
 put / '     (QuadraticCT x LinearTime)MS = ' C3MS;
 put /'     F(QuadCT x LinTime) = ' FC3 'p-value = ' pC3;
 put ///'    (QuadraticCT x QuadraticTime)SS = ' C4;
 put / '     (QuadraticCT x QuadraticTime)MS = ' C4MS;
 put /'     F(QuadCT x QuadTime) = ' FC4 'p-value = ' pC4;
 output;
end;
```

```
run;

/*CT x RT pieces */
proc glm data=one outstat=junk33;
title1 "Split-Split pieces: RTxCT and Linear components";
class RT CT;
model aw=RT|CT/ss3;
contrast "Linear CT" CT -1 0 1;
contrast "LinearCT@RT1" CT -1 0 1 RT*CT -1 0 1;
contrast "LinearCT@RT2" CT -1 0 1 RT*CT 0 0 0 -1 0 1;
run;

proc print data=junk33;
title2 "Do we have <junk33>"; run; /*Yes*/

/*Find RT x LinearCT Contrast*/
data splitsplit3;
set ER junk33;  /*merge Error a/b/c dataset with junk33 */
keep _SOURCE_ DF SS;
proc print;
title2 "Do we have <splitsplit3>"; run; /*Yes*/
run; title2 ' ';

data splitsplit3; set splitsplit3 end=last;
title1 "Split-Split pieces: RT x CT and Linear contrasts";
retain div dfE dfRT dfRTCT RTCT RTLinCT 0;
if _N_ = 3 then dfE=DF; else dfE=dfE+0;      /*This is Error(c) */
if _N_ = 3 then div=SS/DF; else div=div+0;
if _N_ = 5 then dfRT=DF; else dfRT=dfRT+0;  /*df for RTxLinCT*/
if _N_ = 7 then dfRTCT=DF; else dfRTCT=dfRTCT+0; /*df for RTxCT */
if _N_ = 7 then RTCT=SS; else RTCT=RTCT+0; /*RTxCT SS */
if _N_ < 8 then SS=0;
else if _N_ = 8 then SS=-SS;
RTLinCT=RTLinCT+SS;  /* RTxLinCT SS */
if last then do;
  /*to find F and p-values for RTxCT, RTxLinCT */
  RTCTMS=RTCT/dfRTCT;
  FRTCT=RTCTMS/div; pRTCT=1-probf(FRTCT,dfRTCT,dfE);
  RTLinCTMS=RTLinCT/dfRT;
  FRTLinCT=RTLinCTMS/div; pRTLinCT=1-probf(FRTLinCT,dfRT,dfE);
  file print;
  put ///'     (RTxCT)SS = ' RTCT;
  put / '      (RTxCT)MS = ' RTCTMS;
  put /'      F(RTxCT) = ' FRTCT 'p-value = ' pRTCT;
  put ///'     (RT x LinearCT)SS = ' RTLinCT;
  put / '      (RT x LinearCT)MS = ' RTLinCTMS;
  put /'      F(RT x LinCT) = ' FRTLinCT 'p-value = ' pRTLinCT;
  output;
end;
run;

proc glm data=one outstat=junk34;
title1 "Split-Split pieces: RTxCT Quadratic components";
class RT CT;
model aw=RT|CT/ss3;
contrast "Quadratic CT" CT -1 2 -1;
```

```
contrast "QuadraticCT@RT1" CT -1 2 -1 RT*CT -1 2 -1;
contrast "Quadratic@RT2" CT -1 2 -1 RT*CT 0 0 0 -1 2 -1;
run;

proc print data=junk34;
title2 "Do we have <junk34>"; run; /*Yes*/

/*Find RT x QuadCT Contrast*/
data splitsplit4;
set ER junk34;  /*merge Error a/b/c dataset with junk34 */
keep _SOURCE_ DF SS;
proc print;
title2 "Do we have <splitsplit4>"; run; /*Yes*/
run; title2 ' ';

data splitsplit4; set splitsplit4 end=last;
title1 "Split-Split pieces: RT x CT Quadratic contrasts";
retain div dfE dfRT RTQuadCT 0;
if _N_ = 3 then dfE=DF; else dfE=dfE+0;       /*This is Error(c) */
if _N_ = 3 then div=SS/DF; else div=div+0;
if _N_ = 5 then dfRT=DF; else dfRT=dfRT+0;  /*df for RTxQuadCT*/
if _N_ < 8 then SS=0;
else if _N_ = 8 then SS=-SS;
RTQuadCT=RTQuadCT+SS;  /* RTxQuadCT SS */
if last then do;
  /*to find F and p-values for RTxQuadCT */
  RTQuadCTMS=RTQuadCT/dfRT;
  FRTQuadCT=RTQuadCTMS/div; pRTQuadCT=1-probf(FRTQuadCT,dfRT,dfE);
  file print;
  put ///'     (RT x QuadraticCT)SS = ' RTQuadCT;
  put / '      (RT x QuadraticCT)MS = ' RTQuadCTMS;
  put /'      F(RT x QuadraticCT) = ' FRTQuadCT 'p-value = ' pRTQuadCT;
  output;
end;
run;

/*size RT time pieces */
proc glm data=one outstat=junk35;
title1 "Split-Split pieces: size, RT, time and Linear components";
class size RT time;
model aw=size|RT|time/ss3;
contrast "Linear Time" time -1 0 1;
contrast "LinT@size1" time -1 0 1 size*time -1 0 1;
contrast "LinT@size2" time -1 0 1 size*time 0 0 0 -1 0 1;
run;

proc print data=junk35;
title2 "Do we have <junk35>"; run; /*Yes*/

/*Find Size, sizextime, sizexRTxtime*/
data splitsplit5;
set ER junk35;  /*merge Error a/b/c dataset with junk35 */
keep _SOURCE_ DF SS;
proc print;
title2 "Do we have <splitsplit5>"; run; /*Yes*/
run; title2 ' ';
```

```
data splitsplit5; set splitsplit5 end=last;
title1 "Split-Split pieces: size, RT, time and Linear contrasts";
retain div dfE dfS dfSRT dfStime dfSRTtime Size SRT Stime SRTtime SLinT 0;
if _N_ = 3 then dfE=DF; else dfE=dfE+0;      /*This is Error(c) */
if _N_ = 3 then div=SS/DF; else div=div+0;
if _N_ = 5 then dfS=DF; else dfS=dfS+0;  /*df for SizexLinT, size*/
if _N_ = 5 then Size=SS; else Size=Size+0; /* Size SS */
if _N_ = 7 then dfSRT=DF; else dfSRT=dfSRT+0; /*df for sizexRT */
if _N_ = 7 then SRT=SS; else SRT=SRT+0; /*sizexRT SS */
if _N_ = 9 then dfStime=DF; else dfStime=dfStime+0;  /* size x time df */
if _N_ = 9 then Stime=SS; else Stime=Stime+0; /* sizexTime SS */
if _N_ = 11 then dfSRTtime=DF; else dfSRTtime=dfSRTtime+0;  /* df for sizexRTxtime */
if _N_ = 11 then SRTtime=SS; else SRTtime=SRTtime+0;  /* size x RT x time SS */
if _N_ < 12 then SS=0;
else if _N_ = 12 then SS=-SS;
SLinT=SLinT+SS;  /* sizexLinTime SS */
if last then do;
 /*to find F and p-values  */
 SizeMS=Size/dfS;
 FSize=SizeMS/div; pSize=1-probf(FSize,dfS,dfE);
 SRTMS= SRT/dfSRT;
 FSRT=SRTMS/div; pSRT=1-probf(FSRT,dfSRT,dfE);
 StimeMS=Stime/dfStime;
 FStime=StimeMS/div; pStime=1-probf(FStime,dfStime,dfE);
 SRTtimeMS=SRTtime/dfSRTtime;
 FSRTtime=SRTtimeMS/div; pSRTtime=1-probf(FSRTtime,dfSRTtime,dfE);
 SLinTMS=SLinT/dfS;
 FSLinT=SLinTMS/div; pSLinT=1-probf(FSLinT,dfS,dfE);
 file print;
 put ///'    (Size)SS  = ' Size;
 put / '     (Size)MS = ' SizeMS;
 put /'     F(Size) = ' FSize 'p-value = ' pSize;
 put///'    (SizexRT)SS  =  ' SRT;
 put/ '     (SizexRT)MS  =  ' SRTMS;
 put/ '     F(SizexRT)  =  ' FSRT ' p-value = ' pSRT;
 put///'    (SizexTime)SS = ' Stime;
 put/ '     (SizexTime)MS = ' StimeMS;
 put/ '     F(SizexTime)  =  ' FStime '  p-value = ' pStime;
 put///'     (SizexRTxTime)SS = ' SRTtime;
 put/'      (SizexRTxTime)MS = ' SRTtimeMS;
 put/ '     F(SizexRTxTime) = ' FSRTtime  '   p-value = ' pSRTtime;
 put ///'   (Size x LinearT)SS = ' SLinT;
 put / '    (Size x LinearT)MS = ' SLinTMS;
 put /'     F(Size x LinearT) = ' FSLinT 'p-value = ' pSLinT;
 output;
end;
run;

proc glm data=one outstat=junk36;
title1 "Split-Split pieces: size time quadratic components";
class size time;
model aw=size|time/ss3;
contrast "Quadratic Time" time -1 2 -1;
contrast "QuadT@size1" time -1 2 -1 size*time -1 2 -1;
contrast "QuadT@size2" time -1 2 -1 size*time 0 0 0 -1 2 -1;
```

```
run;

proc print data=junk36;
title2 "Do we have <junk36>"; run; /*Yes*/

/*Find size x QuadraticTime Contrast*/
data splitsplit6;
set ER junk36;  /*merge Error a/b/c dataset with junk36 */
keep _SOURCE_ DF SS;
proc print;
title2 "Do we have <splitsplit6>"; run; /*Yes*/
run; title2 ' ';
data splitsplit6; set splitsplit6 end=last;
title1 "Split-Split pieces: Size Time Quadratic contrasts";
retain div dfE dfS SQuadT 0;
if _N_ = 3 then dfE=DF; else dfE=dfE+0;       /*This is Error(c) */
if _N_ = 3 then div=SS/DF; else div=div+0;
if _N_ = 5 then dfS=DF; else dfS=dfS+0;  /*df for SizexQuadT*/
if _N_ < 8 then SS=0;
else if _N_ = 8 then SS=-SS;
SQuadT=SQuadT+SS;  /* SizexQuadT SS */
if last then do;
  /*to find F and p-values for SizexQuadT */
  SQuadTMS=SQuadT/dfS;
  FSQuadT=SQuadTMS/div; pSQuadT=1-probf(FSQuadT,dfS,dfE);
  file print;
  put ///'     (Size x QuadTime)SS = ' SQuadT;
  put / '      (Size x QuadTime)MS = ' SQuadTMS;
  put /'      F(Size x QuadTime) = ' FSQuadT 'p-value = ' pSQuadT;
  output;
end;
run;

/*size CT pieces */
proc glm data=one outstat=junk37;
title1 "Split-Split pieces: size CT Linear components";
class size CT;
model aw=size|CT/ss3;
contrast "Linear CT" CT -1 0 1;
contrast "LinCT@size1" CT -1 0 1 size*CT -1 0 1;
contrast "LinCT@size2" CT -1 0 1 size*CT 0 0 0 -1 0 1;
run;

proc print data=junk37;
title2 "Do we have <junk37>"; run; /*Yes*/

/*Find SizexCT, size x LinearCT Contrast*/
data splitsplit7;
set ER junk37;  /*merge Error a/b/c dataset with junk37 */
keep _SOURCE_ DF SS;
proc print;
title2 "Do we have <splitsplit7>"; run; /*Yes*/
run; title2 ' ';

data splitsplit7; set splitsplit7 end=last;
title1 "Split-Split pieces: size, CT Linear contrasts";
```

```
retain div dfE dfS dfSCT SCT SLinCT 0;
if _N_ = 3 then dfE=DF; else dfE=dfE+0;      /*This is Error(c) */
if _N_ = 3 then div=SS/DF; else div=div+0;
if _N_ = 5 then dfS=DF; else dfS=dfS+0;  /*df for SizexLinCT */
if _N_ = 7 then dfSCT=DF; else dfSCT=dfSCT+0; /*df for sizexCT */
if _N_ = 7 then SCT=SS; else SCT=SCT+0; /*sizexCT SS */
if _N_ < 8 then SS=0;
else if _N_ = 8 then SS=-SS;
SLinCT=SLinCT+SS;  /* sizexLinTime SS */
if last then do;
  /*to find F and p-values  */
  SCTMS= SCT/dfSCT;
  FSCT=SCTMS/div; pSCT=1-probf(FSCT,dfSCT,dfE);
  SLinCTMS=SLinCT/dfS;
  FSLinCT=SLinCTMS/div; pSLinCT=1-probf(FSLinCT,dfS,dfE);
  file print;
  put///'     (SizexCT)SS  =  ' SCT;
  put/ '      (SizexCT)MS  =  ' SCTMS;
  put/ '     F(SizexCT)  =  ' FSCT ' p-value = ' pSCT;
  put ///'    (Size x LinearCT)SS = ' SLinCT;
  put / '     (Size x LinearCT)MS = ' SLinCTMS;
  put /'     F(Size x LinearCT) = ' FSLinCT 'p-value = ' pSLinCT;
  output;
end;
run;

proc glm data=one outstat=junk38;
title1 "Split-Split pieces: size CT quadratic components";
class size CT;
model aw=size|CT/ss3;
contrast "Quadratic CT" CT -1 2 -1;
contrast "QuadCT@size1" CT -1 2 -1 size*CT -1 2 -1;
contrast "QuadCT@size2" CT -1 2 -1 size*CT 0 0 0 -1 2 -1;
run;

proc print data=junk38;
title2 "Do we have <junk38>"; run; /*Yes*/

/*Find size x Quadratic CT Contrast*/
data splitsplit8;
set ER junk38;  /*merge Error a/b/c dataset with junk38 */
keep _SOURCE_ DF SS;
proc print;
title2 "Do we have <splitsplit8>"; run; /*Yes*/
run; title2 ' ';
data splitsplit8; set splitsplit8 end=last;
title1 "Split-Split pieces: Size CT Quadratic contrasts";
retain div dfE dfS SQuadCT 0;
if _N_ = 3 then dfE=DF; else dfE=dfE+0;      /*This is Error(c) */
if _N_ = 3 then div=SS/DF; else div=div+0;
if _N_ = 5 then dfS=DF; else dfS=dfS+0;  /*df for SizexQuadCT*/
if _N_ < 8 then SS=0;
else if _N_ = 8 then SS=-SS;
SQuadCT=SQuadCT+SS;  /* SizexQuadCT SS */
if last then do;
  /*to find F and p-values for SizexQuadCT */
```

```
 SQuadCTMS=SQuadCT/dfS;
 FSQuadCT=SQuadCTMS/div; pSQuadCT=1-probf(FSQuadCT,dfS,dfE);
 file print;
 put ///'    (Size x Quad CT)SS = ' SQuadCT;
 put / '     (Size x Quad CT)MS = ' SQuadCTMS;
 put /'     F(Size x Quad CT) = ' FSQuadCT 'p-value = ' pSQuadCT;
 output;
end;
run;

/*abrade CT pieces */
proc glm data=one outstat=junk39;
title1 "Split-Split pieces: abrade CT Linear components";
class abrade CT;
model aw=abrade|CT/ss3;
contrast "Linear CT" CT -1 0 1;
contrast "LinCT@abrade1" CT -1 0 1 abrade*CT -1 0 1;
contrast "LinCT@abrade2" CT -1 0 1 abrade*CT 0 0 0 -1 0 1;
run;

proc print data=junk39;
title2 "Do we have <junk39>"; run; /*Yes*/

/*Find abrade, abradexCT, abrade x LinearCT Contrast*/
data splitsplit9;
set ER junk39;  /*merge Error a/b/c dataset with junk39 */
keep _SOURCE_ DF SS;
proc print;
title2 "Do we have <splitsplit9>"; run; /*Yes*/
run; title2 ' ';

data splitsplit9; set splitsplit9 end=last;
title1 "Split-Split pieces: Abrade, CT Linear contrasts";
retain div dfE dfAb dfAbCT Ab AbCT AbLinCT 0;
if _N_ = 3 then dfE=DF; else dfE=dfE+0;      /*This is Error(c) */
if _N_ = 3 then div=SS/DF; else div=div+0;
if _N_ = 5 then dfAb=DF; else dfAb=dfAb+0;  /*df for AbradexLinCT, and Abrade */
if _N_ = 5 then Ab=SS; else Ab=Ab+0;  /*Abrade SS*/
if _N_ = 7 then dfAbCT=DF; else dfAbCT=dfAbCT+0; /*df for AbradexCT */
if _N_ = 7 then AbCT=SS; else AbCT=AbCT+0; /*AbradexCT SS */
if _N_ < 8 then SS=0;
else if _N_ = 8 then SS=-SS;
AbLinCT=AbLinCT+SS;  /* abradexLinCT SS */
if last then do;
 /*to find F and p-values  */
 AbMS=Ab/dfAb;
 FAb=AbMS/div; pAb=1-probf(FAb,dfAb,dfE);
 AbCTMS= AbCT/dfAbCT;
 FAbCT=AbCTMS/div; pAbCT=1-probf(FAbCT,dfAbCT,dfE);
 AbLinCTMS=AbLinCT/dfAb;
 FAbLinCT=AbLinCTMS/div; pAbLinCT=1-probf(FAbLinCT,dfAb,dfE);
 file print;
 put///'     (Abrade)SS = ' Ab;
 put/ '      (Abrade)MS = ' AbMS;
 put/ '     F(Abrade) = ' FAb '   p-value = ' pAb;
 put///'     (AbradexCT)SS  =  ' AbCT;
```

```
  put/ '      (AbradexCT)MS  =  ' AbCTMS;
  put/ '     F(AbradexCT)  =  ' FAbCT ' p-value = ' pAbCT;
  put ///'    (Abrade x LinearCT)SS = ' AbLinCT;
  put / '     (Abrade x LinearCT)MS = ' AbLinCTMS;
  put /'     F(Abrade x LinearCT) = ' FAbLinCT 'p-value = ' pAbLinCT;
  output;
end;
run;

proc glm data=one outstat=junk310;
title1 "Split-Split pieces: Abrade CT quadratic components";
class abrade CT;
model aw=abrade|CT/ss3;
contrast "Quadratic CT" CT -1 2 -1;
contrast "QuadCT@abrade1" CT -1 2 -1 abrade*CT -1 2 -1;
contrast "QuadCT@abrade2" CT -1 2 -1 abrade*CT 0 0 0 -1 2 -1;
run;

proc print data=junk310;
title2 "Do we have <junk310>"; run; /*Yes*/

/*Find abrade x Quadratic CT Contrast*/
data splitsplit10;
set ER junk310;  /*merge Error a/b/c dataset with junk310 */
keep _SOURCE_ DF SS;
proc print;
title2 "Do we have <splitsplit10>"; run; /*Yes*/
run; title2 ' ';
data splitsplit10; set splitsplit10 end=last;
title1 "Split-Split pieces: abrade CT Quadratic contrasts";
retain div dfE dfAb AbQuadCT 0;
if _N_ = 3 then dfE=DF; else dfE=dfE+0;      /*This is Error(c) */
if _N_ = 3 then div=SS/DF; else div=div+0;
if _N_ = 5 then dfAb=DF; else dfAb=dfAb+0;  /*df for abradexQuadCT*/
if _N_ < 8 then SS=0;
else if _N_ = 8 then SS=-SS;
AbQuadCT=AbQuadCT+SS;  /* abradexQuadCT SS */
if last then do;
  /*to find F and p-values for abradexQuadCT */
  AbQuadCTMS=AbQuadCT/dfAb;
  FAbQuadCT=AbQuadCTMS/div; pAbQuadCT=1-probf(FAbQuadCT,dfAb,dfE);
  file print;
  put ///'    (abrade x Quad CT)SS = ' AbQuadCT;
  put / '     (abrade x Quad CT)MS = ' AbQuadCTMS;
  put /'     F(abrade x Quad CT) = ' FAbQuadCT 'p-value = ' pAbQuadCT;
  output;
end;
run;

/*abrade time pieces */
proc glm data=one outstat=junk311;
title1 "Split-Split pieces: abrade time Linear components";
class abrade time;
model aw=abrade|time/ss3;
contrast "Linear Time" time -1 0 1;
contrast "LinT@abrade1" time -1 0 1 abrade*time -1 0 1;
```

```
contrast "LinT@abrade2" time -1 0 1 abrade*time 0 0 0 -1 0 1;
run;

proc print data=junk311;
title2 "Do we have <junk311>"; run; /*Yes*/

/*Find abradextime, abrade x LinearTime Contrast*/
data splitsplit11;
set ER junk311;  /*merge Error a/b/c dataset with junk311 */
keep _SOURCE_ DF SS;
proc print;
title2 "Do we have <splitsplit11>"; run; /*Yes*/
run; title2 ' ';

data splitsplit11; set splitsplit11 end=last;
title1 "Split-Split pieces: Abrade, time Linear contrasts";
retain div dfE dfAb dfAbT AbT AbLinT 0;
if _N_ = 3 then dfE=DF; else dfE=dfE+0;      /*This is Error(c) */
if _N_ = 3 then div=SS/DF; else div=div+0;
if _N_ = 5 then dfAb=DF; else dfAb=dfAb+0;  /*df for AbradexLinTime */
if _N_ = 7 then dfAbT=DF; else dfAbT=dfAbT+0; /*df for AbradexT */
if _N_ = 7 then AbT=SS; else AbT=AbT+0; /*AbradexT SS */
if _N_ < 8 then SS=0;
else if _N_ = 8 then SS=-SS;
AbLinT=AbLinT+SS;  /* abradexLinTime SS */
if last then do;
  /*to find F and p-values  */
  AbTMS= AbT/dfAbT;
  FAbT=AbTMS/div; pAbT=1-probf(FAbT,dfAbT,dfE);
  AbLinTMS=AbLinT/dfAb;
  FAbLinT=AbLinTMS/div; pAbLinT=1-probf(FAbLinT,dfAb,dfE);
  file print;
  put///'     (AbradexTime)SS  =  ' AbT;
  put/ '      (AbradexTime)MS  =  ' AbTMS;
  put/ '     F(AbradexTime)  =  ' FAbT ' p-value = ' pAbT;
  put ///'    (Abrade x LinearTime)SS = ' AbLinT;
  put / '     (Abrade x LinearTime)MS = ' AbLinTMS;
  put /'     F(Abrade x LinearTime) = ' FAbLinT 'p-value = ' pAbLinT;
  output;
end;
run;

proc glm data=one outstat=junk312;
title1 "Split-Split pieces: Abrade time quadratic components";
class abrade time;
model aw=abrade|time/ss3;
contrast "Quadratic Time" time -1 2 -1;
contrast "QuadT@abrade1" time -1 2 -1 abrade*time -1 2 -1;
contrast "QuadT@abrade2" time -1 2 -1 abrade*time 0 0 0 -1 2 -1;
run;

proc print data=junk312;
title2 "Do we have <junk312>"; run; /*Yes*/

/*Find abrade x Quadratic time Contrast*/
data splitsplit12;
```

```
set ER junk312;  /*merge Error a/b/c dataset with junk312 */
keep _SOURCE_ DF SS;
proc print;
title2 "Do we have <splitsplit12>"; run; /*Yes*/
run; title2 ' ';
data splitsplit12; set splitsplit12 end=last;
title1 "Split-Split pieces: abrade time Quadratic contrasts";
retain div dfE dfAb AbQuadT 0;
if _N_ = 3 then dfE=DF; else dfE=dfE+0;      /*This is Error(c) */
if _N_ = 3 then div=SS/DF; else div=div+0;
if _N_ = 5 then dfAb=DF; else dfAb=dfAb+0;  /*df for abradexQuadT*/
if _N_ < 8 then SS=0;
else if _N_ = 8 then SS=-SS;
AbQuadT=AbQuadT+SS;  /* abradexQuadT SS */
if last then do;
  /*to find F and p-values for abradexQuadT */
  AbQuadTMS=AbQuadT/dfAb;
  FAbQuadT=AbQuadTMS/div; pAbQuadT=1-probf(FAbQuadT,dfAb,dfE);
  file print;
  put ///'     (abrade x Quad Time)SS = ' AbQuadT;
  put / '      (abrade x Quad Time)MS = ' AbQuadTMS;
  put /'      F(abrade x Quad Time) = ' FAbQuadT 'p-value = ' pAbQuadT;
  output;
end;
run;

/*The rest of the story... pieces */
proc glm data=one outstat=junk313;
title1 "Split-Split pieces: not previously covered";
class CT RT time size abrade;
model aw=CT*RT*time size*RT size*CT*time size*RT*time size*CT*RT size*CT*RT*time
   abrade*RT abrade*RT*time abrade*CT*time abrade*CT*RT  abrade*CT*RT*time
   abrade*size abrade*size*time abrade*size*RT abrade*size*RT*time
   abrade*size*CT abrade*size*CT*time abrade*size*CT*RT
   abrade*size*CT*RT*time/ss3;

run;

proc print data=junk313;
title2 "Do we have <junk313>"; run; /*Yes*/

/*Rest of values*/
data splitsplit13;
set junk313 ER;  /*merge Error a/b/c dataset with junk313 */
keep _SOURCE_ DF SS; output;
proc print;
title2 "Do we have <splitsplit13>"; run; /*Yes*/
run; title2 ' ';

proc iml;
use splitsplit13;
read all var {DF SS} into P;
nr=nrow(P);
FM=J(nr,5,0);
FM[1:nr,1:2]=P[1:nr,1:2];
do r = 1 to nr;
```

```
   FM[r,3]=FM[r,2]/FM[r,1];
end;
MSEc=FM[nr,3]; dfE=FM[nr,1];
/*print P FM MSEc; */
do r = 1 to nr;
   FM[r,4]=FM[r,3]/MSEc;
          FM[r,5]=1-probf(FM[r,4],FM[r,1],dfE);
end;
/*print MSEc dfE FM; */
varnames={DF SS MS F p};
create outFP from FM (|colname=varnames|);
append from FM;
run;

data yes;
merge splitsplit13 outFP;
proc print data=yes;
title2 "The rest of the F and p values"; run;
quit;
```

OUTPUT

Batch Vacuum-belt Drying Analysis 23 May 2010 1
The GLM Procedure

Class Level Information

Class	Levels	Values
rep	9	1 2 3 4 5 6 7 8 9
abrade	2	1 2
size	2	1 2
CT	3	1 2 3
RT	2	1 2
time	3	1 2 3

Number of Observations Read 648
Number of Observations Used 648

Batch Vacuum-belt Drying Analysis 23 May 2010 2
The GLM Procedure

Dependent Variable: aw

Source	DF	Sum of Squares	Mean Square	F Value
Model	647	39.15074235	0.06051119	.
Error	0	0.00000000	.	
Corrected Total	647	39.15074235		

Source	Pr > F
Model	.
Error	
Corrected Total	

R-Square	Coeff Var	Root MSE	aw Mean

1.000000 . . 0.568235

Source	DF	Type III SS	Mean Square	F Value
time	2	5.71563683	2.85781841	.
RT	1	1.41400139	1.41400139	.
RT*time	2	0.03698878	0.01849439	.
CT	2	15.50202237	7.75101119	.
CT*time	4	0.74884215	0.18721054	.
CT*RT	2	0.30961623	0.15480812	.
CT*RT*time	4	0.80102244	0.20025561	.
size	1	0.09709356	0.09709356	.
size*time	2	0.06168933	0.03084467	.

Source	Pr > F
time	.
RT	.
RT*time	.
CT	.
CT*time	.
CT*RT	.
CT*RT*time	.
size	.
size*time	.

The GLM Procedure

Dependent Variable: aw

Source	DF	Type III SS	Mean Square	F Value
size*RT	1	0.00329852	0.00329852	.
size*RT*time	2	0.07605279	0.03802640	.
size*CT	2	0.05410408	0.02705204	.
size*CT*time	4	0.07967669	0.01991917	.
size*CT*RT	2	0.13953604	0.06976802	.
size*CT*RT*time	4	0.32344759	0.08086190	.
abrade	1	0.35504356	0.35504356	.
abrade*time	2	0.25055515	0.12527757	.
abrade*RT	1	0.11418890	0.11418890	.
abrade*RT*time	2	0.10348083	0.05174041	.
abrade*CT	2	0.00497003	0.00248501	.
abrade*CT*time	4	0.29682616	0.07420654	.
abrade*CT*RT	2	0.07668910	0.03834455	.
abrade*CT*RT*time	4	0.41036990	0.10259248	.
abrade*size	1	0.05644800	0.05644800	.
abrade*size*time	2	0.02543748	0.01271874	.
abrade*size*RT	1	0.05102238	0.05102238	.
abrade*size*RT*time	2	0.38122820	0.19061410	.
abrade*size*CT	2	0.01573879	0.00786939	.
abrade*size*CT*time	4	0.31567195	0.07891799	.
abrade*size*CT*RT	2	0.00281363	0.00140682	.
abra*size*CT*RT*time	4	0.10269640	0.02567410	.
rep	8	1.26421860	0.15802732	.
rep*time	16	0.25392151	0.01587009	.
rep*RT	8	0.12730392	0.01591299	.
rep*RT*time	16	0.25799800	0.01612488	.
rep*CT	16	0.30630296	0.01914393	.
rep*CT*time	32	0.44356069	0.01386127	.
rep*CT*RT	16	0.14337288	0.00896080	.
rep*CT*RT*time	32	0.47093662	0.01471677	.
rep*size	8	0.08571114	0.01071389	.
rep*size*time	16	0.11875622	0.00742226	.
rep*size*RT	8	0.06067600	0.00758450	.
rep*size*RT*time	16	0.40500443	0.02531278	.
rep*size*CT	16	0.44636164	0.02789760	.
rep*size*CT*time	32	0.49743508	0.01554485	.
rep*size*CT*RT	16	0.27752768	0.01734548	.
rep*size*CT*RT*time	32	0.65068519	0.02033391	.

rep*abrade	8	0.11438581	0.01429823	.
rep*abrade*time	16	0.22607607	0.01412975	.
rep*abrade*RT	8	0.20085785	0.02510723	.
rep*abrade*RT*time	16	0.12029884	0.00751868	.
rep*abrade*CT	16	0.49900886	0.03118805	.
rep*abrade*CT*time	32	1.12368062	0.03511502	.
rep*abrade*CT*RT	16	0.16811390	0.01050712	.
rep*abrad*CT*RT*time	32	0.45749443	0.01429670	.

Batch Vacuum-belt Drying Analysis 23 May 2010 4
The GLM Procedure

Dependent Variable: aw

Source	Pr > F
size*RT	.
size*RT*time	.
size*CT	.
size*CT*time	.
size*CT*RT	.
size*CT*RT*time	.
abrade	.
abrade*time	.
abrade*RT	.
abrade*RT*time	.
abrade*CT	.
abrade*CT*time	.
abrade*CT*RT	.
abrade*CT*RT*time	.
abrade*size	.
abrade*size*time	.
abrade*size*RT	.
abrade*size*RT*time	.
abrade*size*CT	.
abrade*size*CT*time	.
abrade*size*CT*RT	.
abra*size*CT*RT*time	.
rep	.
rep*time	.
rep*RT	.
rep*RT*time	.
rep*CT	.
rep*CT*time	.
rep*CT*RT	.
rep*CT*RT*time	.
rep*size	.
rep*size*time	.
rep*size*RT	.
rep*size*RT*time	.
rep*size*CT	.
rep*size*CT*time	.
rep*size*CT*RT	.
rep*size*CT*RT*time	.
rep*abrade	.
rep*abrade*time	.
rep*abrade*RT	.
rep*abrade*RT*time	.
rep*abrade*CT	.
rep*abrade*CT*time	.
rep*abrade*CT*RT	.
rep*abrad*CT*RT*time	.

Batch Vacuum-belt Drying Analysis 23 May 2010 5
The GLM Procedure

Dependent Variable: aw

Source	DF	Type III SS	Mean Square	F Value

rep*abrade*size	8	0.05694114	0.00711764 .
rep*abrade*size*time	16	0.36801763	0.02300110 .
rep*abrade*size*RT	8	0.05802493	0.00725312 .
rep*abr*size*RT*time	16	0.21734658	0.01358416 .
rep*abrade*size*CT	16	0.31965416	0.01997838 .
rep*abr*size*CT*time	32	0.38558610	0.01204957 .
rep*abrad*size*CT*RT	16	0.19094831	0.01193427 .
re*abr*siz*CT*RT*tim	32	0.90832532	0.02838517 .

Source	Pr > F
rep*abrade*size	.
rep*abrade*size*time	.
rep*abrade*size*RT	.
rep*abr*size*RT*time	.
rep*abrade*size*CT	.
rep*abr*size*CT*time	.
rep*abrad*size*CT*RT	.
re*abr*siz*CT*RT*tim	.

Batch Vacuum-belt Drying Analysis 23 May 2010 6
The GLM Procedure

Level of time	N	aw Mean	aw Std Dev
1	216	0.68949074	0.22831659
2	216	0.55454630	0.24051951
3	216	0.46066667	0.21338702

Level of RT	N	aw Mean	aw Std Dev
1	324	0.61494753	0.25228516
2	324	0.52152160	0.23061703

Level of CT	N	aw Mean	aw Std Dev
1	216	0.77180093	0.19578988
2	216	0.53576852	0.21688396
3	216	0.39713426	0.15691309

Level of size	N	aw Mean	aw Std Dev
1	324	0.55599383	0.24827311
2	324	0.58047531	0.24345347

Level of abrade	N	aw Mean	aw Std Dev
1	324	0.59164198	0.24668531
2	324	0.54482716	0.24342736

RT qual, Time quantitative; SOURCE, DF & SS data only....contrasts 7

Obs	_SOURCE_	DF	SS
1	ERROR	0	0.0000
2	time	2	5.7156
3	RT	1	1.4140
4	RT*time	2	0.0370
5	CT	2	15.5020
6	CT*time	4	0.7488

7	CT*RT	2	0.3096
8	CT*RT*time	4	0.8010
9	size	1	0.0971
10	size*time	2	0.0617
11	size*RT	1	0.0033
12	size*RT*time	2	0.0761
13	size*CT	2	0.0541
14	size*CT*time	4	0.0797
15	size*CT*RT	2	0.1395
16	size*CT*RT*time	4	0.3234
17	abrade	1	0.3550
18	abrade*time	2	0.2506
19	abrade*RT	1	0.1142
20	abrade*RT*time	2	0.1035
21	abrade*CT	2	0.0050
22	abrade*CT*time	4	0.2968
23	abrade*CT*RT	2	0.0767
24	abrade*CT*RT*time	4	0.4104
25	abrade*size	1	0.0564
26	abrade*size*time	2	0.0254
27	abrade*size*RT	1	0.0510
28	abrade*size*RT*time	2	0.3812
29	abrade*size*CT	2	0.0157
30	abrade*size*CT*time	4	0.3157
31	abrade*size*CT*RT	2	0.0028
32	abra*size*CT*RT*time	4	0.1027
33	rep	8	1.2642
34	rep*time	16	0.2539
35	rep*RT	8	0.1273
36	rep*RT*time	16	0.2580
37	rep*CT	16	0.3063
38	rep*CT*time	32	0.4436
39	rep*CT*RT	16	0.1434
40	rep*CT*RT*time	32	0.4709
41	rep*size	8	0.0857
42	rep*size*time	16	0.1188
43	rep*size*RT	8	0.0607
44	rep*size*RT*time	16	0.4050
45	rep*size*CT	16	0.4464
46	rep*size*CT*time	32	0.4974
47	rep*size*CT*RT	16	0.2775
48	rep*size*CT*RT*time	32	0.6507
49	rep*abrade	8	0.1144
50	rep*abrade*time	16	0.2261

RT qual, Time quantitative; SOURCE, DF & SS data only....contrasts 8

Obs	_SOURCE_	DF	SS
51	rep*abrade*RT	8	0.20086
52	rep*abrade*RT*time	16	0.12030
53	rep*abrade*CT	16	0.49901
54	rep*abrade*CT*time	32	1.12368
55	rep*abrade*CT*RT	16	0.16811
56	rep*abrad*CT*RT*time	32	0.45749
57	rep*abrade*size	8	0.05694
58	rep*abrade*size*time	16	0.36802
59	rep*abrade*size*RT	8	0.05802
60	rep*abr*size*RT*time	16	0.21735
61	rep*abrade*size*CT	16	0.31965
62	rep*abr*size*CT*time	32	0.38559
63	rep*abrad*size*CT*RT	16	0.19095
64	re*abr*siz*CT*RT*tim	32	0.90833

RT qual, Time quantitative; SOURCE, DF & SS data only....contrasts 9
06:58 Wednesday, August 3, 2005

ER	EC
16 0.2539215	16 0.306303

24 0.3853019 32 0.4435607
528 9.3210911 16 0.1433729
32 0.4709366
8 0.0857111
16 0.1187562
8 0.060676
16 0.4050044
16 0.4463616
32 0.4974351
16 0.2775277
32 0.6506852
8 0.1143858
16 0.2260761
8 0.2008579
16 0.1202988
16 0.4990089
32 1.1236806
16 0.1681139
32 0.4574944
8 0.0569411
16 0.3680176
8 0.0580249
16 0.2173466
16 0.3196542
32 0.3855861
16 0.1909483
32 0.9083253

Is this two2 10

Obs	_SOURCE_	DF	SS
1	ERROR	0	0.0000
2	time	2	5.7156
3	RT	1	1.4140
4	RT*time	2	0.0370
5	CT	2	15.5020
6	CT*time	4	0.7488
7	CT*RT	2	0.3096
8	CT*RT*time	4	0.8010
9	size	1	0.0971
10	size*time	2	0.0617
11	size*RT	1	0.0033
12	size*RT*time	2	0.0761
13	size*CT	2	0.0541
14	size*CT*time	4	0.0797
15	size*CT*RT	2	0.1395
16	size*CT*RT*time	4	0.3234
17	abrade	1	0.3550
18	abrade*time	2	0.2506
19	abrade*RT	1	0.1142
20	abrade*RT*time	2	0.1035
21	abrade*CT	2	0.0050
22	abrade*CT*time	4	0.2968
23	abrade*CT*RT	2	0.0767
24	abrade*CT*RT*time	4	0.4104
25	abrade*size	1	0.0564
26	abrade*size*time	2	0.0254
27	abrade*size*RT	1	0.0510
28	abrade*size*RT*time	2	0.3812
29	abrade*size*CT	2	0.0157
30	abrade*size*CT*time	4	0.3157
31	abrade*size*CT*RT	2	0.0028
32	abra*size*CT*RT*time	4	0.1027
33	rep	8	1.2642
34	rep*time	16	0.2539
35	rep*RT	8	0.1273
36	rep*RT*time	16	0.2580
37	rep*CT	16	0.3063
38	rep*CT*time	32	0.4436

39	rep*CT*RT	16	0.1434
40	rep*CT*RT*time	32	0.4709
41	rep*size	8	0.0857
42	rep*size*time	16	0.1188
43	rep*size*RT	8	0.0607
44	rep*size*RT*time	16	0.4050
45	rep*size*CT	16	0.4464
46	rep*size*CT*time	32	0.4974
47	rep*size*CT*RT	16	0.2775
48	rep*size*CT*RT*time	32	0.6507
49	rep*abrade	8	0.1144
50	rep*abrade*time	16	0.2261

Is this two2 11

Obs	_SOURCE_	DF	SS
51	rep*abrade*RT	8	0.20086
52	rep*abrade*RT*time	16	0.12030
53	rep*abrade*CT	16	0.49901
54	rep*abrade*CT*time	32	1.12368
55	rep*abrade*CT*RT	16	0.16811
56	rep*abrad*CT*RT*time	32	0.45749
57	rep*abrade*size	8	0.05694
58	rep*abrade*size*time	16	0.36802
59	rep*abrade*size*RT	8	0.05802
60	rep*abr*size*RT*time	16	0.21735
61	rep*abrade*size*CT	16	0.31965
62	rep*abr*size*CT*time	32	0.38559
63	rep*abrad*size*CT*RT	16	0.19095
64	re*abr*siz*CT*RT*tim	32	0.90833
65	ERRORA	16	0.25392
66	ERRORB	24	0.38530
67	ERRORC	528	9.32109

Whole Plot pieces: Time and reps 12
The GLM Procedure

Class Level Information

Class	Levels	Values
time	3	1 2 3
rep	9	1 2 3 4 5 6 7 8 9

Number of Observations Read	648
Number of Observations Used	648

Whole Plot pieces: Time and reps 13
The GLM Procedure

Dependent Variable: aw

Source	DF	Sum of Squares	Mean Square	F Value
Model	26	7.23377693	0.27822219	5.41
Error	621	31.91696542	0.05139608	
Corrected Total	647	39.15074235		

Source	Pr > F
Model	<.0001
Error	
Corrected Total	

R-Square	Coeff Var	Root MSE	aw Mean
0.184767	39.89673	0.226707	0.568235

Source	DF	Type III SS	Mean Square	F Value
time	2	5.71563683	2.85781841	55.60
rep	8	1.26421860	0.15802732	3.07
time*rep	16	0.25392151	0.01587009	0.31

Source	Pr > F
time	<.0001
rep	0.0021
time*rep	0.9959

Contrast	DF	Contrast SS	Mean Square	F Value
Linear Time	1	5.65492934	5.65492934	110.03
Quad Time	1	0.06070748	0.06070748	1.18

Contrast	Pr > F
Linear Time	<.0001
Quad Time	0.2775

Whole Plot pieces: Time and reps 14
The GLM Procedure

Dependent Variable: aw

Tests of Hypotheses Using the Type III
MS for time*rep as an Error Term

Source	DF	Type III SS	Mean Square	F Value
time	2	5.71563683	2.85781841	180.08
rep	8	1.26421860	0.15802732	9.96

Tests of Hypotheses Using
the Type III MS for time*rep
as an Error Term

Source	Pr > F
time	<.0001
rep	<.0001

Whole Plot pieces: Time and reps 15
Do we have <junk1>

Obs	_NAME_	_SOURCE_	_TYPE_	DF	SS	F	PROB
1	aw	ERROR	ERROR	621	31.9170	.	.
2	aw	time	SS3	2	5.7156	55.604	0.00000
3	aw	rep	SS3	8	1.2642	3.075	0.00209
4	aw	time*rep	SS3	16	0.2539	0.309	0.99587
5	aw	Linear Time	CONTRAST	1	5.6549	110.026	0.00000
6	aw	Quad Time	CONTRAST	1	0.0607	1.181	0.27754

Whole Plot pieces: Time and reps 16
Time contrasts

(LinearTime)SS = 5.6549293426

(LinearTime)MS = 5.6549293426

F(LinT) = 356.32613734 p-value = 2.328804E-12

(QuadTime)SS = 0.0607074846

(QuadTime)MS = 0.0607074846

F(QuadT) = 3.8252756441 p-value = 0.0681779154

Split plot pieces: RT, RTxTime 17

The GLM Procedure

Class Level Information

Class	Levels	Values
RT	2	1 2
time	3	1 2 3

Number of Observations Read 648
Number of Observations Used 648

Split plot pieces: RT, RTxTime 18

The GLM Procedure

Dependent Variable: aw

Source	DF	Sum of Squares	Mean Square	F Value
Model	5	7.16662699	1.43332540	28.77
Error	642	31.98411535	0.04981949	
Corrected Total	647	39.15074235		

Source	Pr > F
Model	<.0001
Error	
Corrected Total	

R-Square	Coeff Var	Root MSE	aw Mean
0.183052	39.28005	0.223203	0.568235

Source	DF	Type III SS	Mean Square	F Value
RT	1	1.41400139	1.41400139	28.38
time	2	5.71563683	2.85781841	57.36
RT*time	2	0.03698878	0.01849439	0.37

Source	Pr > F
RT	<.0001
time	<.0001
RT*time	0.6900

Contrast	DF	Contrast SS	Mean Square	F Value
Linear Time	1	5.65492934	5.65492934	113.51
LinTime@RT1	1	3.22715557	3.22715557	64.78
LinTime@RT2	1	2.45418785	2.45418785	49.26

Contrast	Pr > F
Linear Time	<.0001
LinTime@RT1	<.0001
LinTime@RT2	<.0001

Split plot pieces: RT, RTxTime 19

Do we have <split1>

Obs	DF	SS	_SOURCE_

1	16	0.2539	ERRORA
2	24	0.3853	ERRORB
3	528	9.3211	ERRORC
4	642	31.9841	ERROR
5	1	1.4140	RT
6	2	5.7156	time
7	2	0.0370	RT*tim
8	1	5.6549	Linear
9	1	3.2272	LinTim
10	1	2.4542	LinTim

Split Plot pieces: RT, RT*Time and Linear contrasts 20

(RT)SS = 1.4140013889

(RT)MS = 1.4140013889

F(RT) = 88.076471633 p-value = 1.6732219E-9

(RTxTime)SS = 0.0369887778

(RTxTime)MS = 0.0184943889

F(RTxTime) = 1.1519935773 p-value = 0.3328709498

(RT x LinearTime)SS = 0.0264140833

(RT x LinearTime)MS = 0.0264140833

F(RT x LinT) = 1.6453019634 p-value = 0.2118498586

Split Plot pieces: RT by Quad Time contrasts 21

The GLM Procedure

Class Level Information

Class	Levels	Values
RT	2	1 2
time	3	1 2 3

Number of Observations Read 648
Number of Observations Used 648

Split Plot pieces: RT by Quad Time contrasts 22

The GLM Procedure

Dependent Variable: aw

Source	DF	Sum of Squares	Mean Square	F Value
Model	5	7.16662699	1.43332540	28.77
Error	642	31.98411535	0.04981949	
Corrected Total	647	39.15074235		

Source	Pr > F
Model	<.0001
Error	
Corrected Total	

R-Square	Coeff Var	Root MSE	aw Mean

0.183052 39.28005 0.223203 0.568235

Source	DF	Type III SS	Mean Square	F Value
RT	1	1.41400139	1.41400139	28.38
time	2	5.71563683	2.85781841	57.36
RT*time	2	0.03698878	0.01849439	0.37

Source	Pr > F
RT	<.0001
time	<.0001
RT*time	0.6900

Contrast	DF	Contrast SS	Mean Square	F Value
Quad Time	1	0.06070748	0.06070748	1.22
QuadTime@RT1	1	0.06097808	0.06097808	1.22
QuadTime@RT2	1	0.01030410	0.01030410	0.21

Contrast	Pr > F
Quad Time	0.2701
QuadTime@RT1	0.2690
QuadTime@RT2	0.6494

Split Plot pieces: RT by Quad Time contrasts 23
Do we have <split2>

Obs	DF	SS	_SOURCE_
1	16	0.2539	ERRORA
2	24	0.3853	ERRORB
3	528	9.3211	ERRORC
4	642	31.9841	ERROR
5	1	1.4140	RT
6	2	5.7156	time
7	2	0.0370	RT*tim
8	1	0.0607	Quad T
9	1	0.0610	QuadTi
10	1	0.0103	QuadTi

Split Plot pieces: RT by Quad Time contrast 24

(RT x QuadTime)SS = 0.0105746944

(RT x QuadTime)MS = 0.0105746944

F(RT x QuadT) = 0.6586851912 p-value = 0.4250010245

Split-Split pieces: CT, and CT contrasts 25

The GLM Procedure

Class Level Information

Class	Levels	Values
CT	3	1 2 3

Number of Observations Read 648
Number of Observations Used 648

Split-Split pieces: CT, and CT contrasts 26
The GLM Procedure

Dependent Variable: aw

Source	DF	Sum of Squares	Mean Square	F Value

Model 2 15.50202237 7.75101119 211.40

Error 645 23.64871997 0.03666468

Corrected Total 647 39.15074235

Source	Pr > F
Model	<.0001
Error	
Corrected Total	

R-Square	Coeff Var	Root MSE	aw Mean
0.395957	33.69739	0.191480	0.568235

Source	DF	Type III SS	Mean Square	F Value
CT	2	15.50202237	7.75101119	211.40

Source	Pr > F
CT	<.0001

Contrast	DF	Contrast SS	Mean Square	F Value
Linear CT	1	15.16051200	15.16051200	413.49
Quad CT	1	0.34151037	0.34151037	9.31

Contrast	Pr > F
Linear CT	<.0001
Quad CT	0.0024

Split-Split pieces: CT, and CT contrasts 27
Do we have <junk3>

Obs	_NAME_	_SOURCE_	_TYPE_	DF	SS	F	PROB
1	aw	ERROR	ERROR	645	23.6487	.	.
2	aw	CT	SS3	2	15.5020	211.403	2.4792E-71
3	aw	Linear CT	CONTRAST	1	15.1605	413.491	2.0964E-71
4	aw	Quad CT	CONTRAST	1	0.3415	9.314	.002367007

Split-Split pieces: CT, and CT contrasts 28
Do we have <splitsplit>

Obs	DF	SS	_SOURCE_
1	16	0.2539	ERRORA
2	24	0.3853	ERRORB
3	528	9.3211	ERRORC
4	645	23.6487	ERROR
5	2	15.5020	CT
6	1	15.1605	Linear
7	1	0.3415	Quad C

Split-Split pieces: CT, and CT contrasts 29

(CT)SS = 15.502022373

(CT)MS = 7.7510111867

F(CT) = 439.06167915 p-value = 0

(Linear CT)SS = 15.160512

(Linear CT)MS = 15.160512

F(LinCT) = 858.77825423 p-value = 0

(Quad CT)SS = 0.3415103735

(Quad CT)MS = 0.3415103735

F(Quad CT) = 19.345104065 p-value = 0.0000132012

Split-Split pieces: CT x Time contrasts 30

The GLM Procedure

Class Level Information

Class	Levels	Values
CT	3	1 2 3
time	3	1 2 3

Number of Observations Read 648
Number of Observations Used 648

Split-Split pieces: CT x Time contrasts 31

06:58 Wednesday, August 3, 2005

The GLM Procedure

Dependent Variable: aw

Source	DF	Sum of Squares	Mean Square	F Value
Model	8	21.96650135	2.74581267	102.10
Error	639	17.18424100	0.02689240	
Corrected Total	647	39.15074235		

Source	Pr > F
Model	<.0001
Error	
Corrected Total	

R-Square	Coeff Var	Root MSE	aw Mean
0.561075	28.85939	0.163989	0.568235

Source	DF	Type III SS	Mean Square	F Value
CT	2	15.50202237	7.75101119	288.22
time	2	5.71563683	2.85781841	106.27
CT*time	4	0.74884215	0.18721054	6.96

Source	Pr > F
CT	<.0001
time	<.0001
CT*time	<.0001

Contrast	DF	Contrast SS	Mean Square	F Value
LinCTxLinTime	1	0.20785128	0.20785128	7.73
LinCTxQuadTime	1	0.31912734	0.31912734	11.87
QuadCTxLinTime	1	0.11272820	0.11272820	4.19

Contrast	Pr > F
LinCTxLinTime	0.0056
LinCTxQuadTime	0.0006

QuadCTxLinTime 0.0410

Split-Split pieces: CT x Time contrasts 32

The GLM Procedure

Dependent Variable: aw

Contrast	DF	Contrast SS	Mean Square	F Value
QuadCTxQuadTime	1	0.10913532	0.10913532	4.06

Contrast	Pr > F
QuadCTxQuadTime	0.0444

Split-Split pieces: CT x Time contrasts 33
Do we have <junk32>

Obs	_NAME_	_SOURCE_	_TYPE_	DF	SS	F	PROB
1	aw	ERROR	ERROR	639	17.1842	.	.
2	aw	CT	SS3	2	15.5020	288.223	0.000000
3	aw	time	SS3	2	5.7156	106.269	0.000000
4	aw	CT*time	SS3	4	0.7488	6.961	0.000017
5	aw	LinCTxLinTime	CONTRAST	1	0.2079	7.729	0.005594
6	aw	LinCTxQuadTime	CONTRAST	1	0.3191	11.867	0.000609
7	aw	QuadCTxLinTime	CONTRAST	1	0.1127	4.192	0.041028
8	aw	QuadCTxQuadTime	CONTRAST	1	0.1091	4.058	0.044375

Split-Split pieces: CT x Time contrasts 34
Do we have <splitsplit2>

Obs	DF	SS	_SOURCE_
1	16	0.2539	ERRORA
2	24	0.3853	ERRORB
3	528	9.3211	ERRORC
4	639	17.1842	ERROR
5	2	15.5020	CT
6	2	5.7156	time
7	4	0.7488	CT*tim
8	1	0.2079	LinCTx
9	1	0.3191	LinCTx
10	1	0.1127	QuadCT
11	1	0.1091	QuadCT

Split-Split pieces: CT, CT x Time contrasts 35

(CT x Time)SS = 0.7488421451

(CT x Time)MS = 0.1872105363

F(CT x Time) = 10.604677303 p-value = 2.8493563E-8

(LinearCT x LinearTime)SS = 0.2078512812

(LinearCT x LinearTime)MS = 0.2078512812

F(LinCT x LinTime) = 11.77388735 p-value = 0.0006477344

(LinearCT x Quadratic Time)SS = 0.3191273437

(LinearCT x Quadratic Time)MS = 0.3191273437

F(LinCT x QuadTime) = 18.07720103 p-value = 0.0000250879

(QuadraticCT x LinearTime)SS = 0.1127281956

(QuadraticCT x LinearTime)MS = 0.1127281956

F(QuadCT x LinTime) = 6.3855708185 p-value = 0.0117960768

(QuadraticCT x QuadraticTime)SS = 0.1091353245

(QuadraticCT x QuadraticTime)MS = 0.1091353245

F(QuadCT x QuadTime) = 6.1820500135 p-value = 0.0132132861

Split-Split pieces: RTxCT and Linear components 36
The GLM Procedure

Class Level Information

Class	Levels	Values
RT	2	1 2
CT	3	1 2 3

Number of Observations Read 648
Number of Observations Used 648

Split-Split pieces: RTxCT and Linear components 37
The GLM Procedure

Dependent Variable: aw

Source	DF	Sum of Squares	Mean Square	F Value
Model	5	17.22563999	3.44512800	100.88
Error	642	21.92510235	0.03415125	
Corrected Total	647	39.15074235		

Source	Pr > F
Model	<.0001
Error	
Corrected Total	

R-Square	Coeff Var	Root MSE	aw Mean
0.439982	32.52188	0.184801	0.568235

Source	DF	Type III SS	Mean Square	F Value
RT	1	1.41400139	1.41400139	41.40
CT	2	15.50202237	7.75101119	226.96
RT*CT	2	0.30961623	0.15480812	4.53

Source	Pr > F
RT	<.0001
CT	<.0001
RT*CT	0.0111

Contrast	DF	Contrast SS	Mean Square	F Value
Linear CT	1	15.16051200	15.16051200	443.92
LinearCT@RT1	1	9.32714456	9.32714456	273.11
LinearCT@RT2	1	6.01434189	6.01434189	176.11

Contrast	Pr > F
Linear CT	<.0001

LinearCT@RT1 <.0001
LinearCT@RT2 <.0001

Split-Split pieces: RTxCT and Linear components 38
Do we have <junk33>

Obs	_NAME_	_SOURCE_	_TYPE_	DF	SS	F	PROB
1	aw	ERROR	ERROR	642	21.9251	.	.
2	aw	RT	SS3	1	1.4140	41.404	0.000000
3	aw	CT	SS3	2	15.5020	226.961	0.000000
4	aw	RT*CT	SS3	2	0.3096	4.533	0.011094
5	aw	Linear CT	CONTRAST	1	15.1605	443.923	0.000000
6	aw	LinearCT@RT1	CONTRAST	1	9.3271	273.113	0.000000
7	aw	LinearCT@RT2	CONTRAST	1	6.0143	176.109	0.000000

Split-Split pieces: RTxCT and Linear components 39
Do we have <splitsplit3>

Obs	DF	SS	_SOURCE_
1	16	0.2539	ERRORA
2	24	0.3853	ERRORB
3	528	9.3211	ERRORC
4	642	21.9251	ERROR
5	1	1.4140	RT
6	2	15.5020	CT
7	2	0.3096	RT*CT
8	1	15.1605	Linear
9	1	9.3271	Linear
10	1	6.0143	Linear

Split-Split pieces: RT x CT and Linear contrasts 40

(RTxCT)SS = 0.3096162315

(RTxCT)MS = 0.1548081157

F(RTxCT) = 8.769218571 p-value = 0.0001792511

(RT x LinearCT)SS = 0.1809744537

(RT x LinearCT)MS = 0.1809744537

F(RT x LinCT) = 10.25142986 p-value = 0.001448042

Split-Split pieces: RTxCT Quadratic components 41

The GLM Procedure

Class Level Information

Class	Levels	Values
RT	2	1 2
CT	3	1 2 3

Number of Observations Read 648
Number of Observations Used 648

Split-Split pieces: RTxCT Quadratic components 42
The GLM Procedure

Dependent Variable: aw

Source	DF	Sum of Squares	Mean Square	F Value
Model	5	17.22563999	3.44512800	100.88

Error 642 21.92510235 0.03415125

Corrected Total 647 39.15074235

Source	Pr > F
Model	<.0001
Error	
Corrected Total	

R-Square	Coeff Var	Root MSE	aw Mean
0.439982	32.52188	0.184801	0.568235

Source	DF	Type III SS	Mean Square	F Value
RT	1	1.41400139	1.41400139	41.40
CT	2	15.50202237	7.75101119	226.96
RT*CT	2	0.30961623	0.15480812	4.53

Source	Pr > F
RT	<.0001
CT	<.0001
RT*CT	0.0111

Contrast	DF	Contrast SS	Mean Square	F Value
Quadratic CT	1	0.34151037	0.34151037	10.00
QuadraticCT@RT1	1	0.02547526	0.02547526	0.75
Quadratic@RT2	1	0.44467689	0.44467689	13.02

Contrast	Pr > F
Quadratic CT	0.0016
QuadraticCT@RT1	0.3881
Quadratic@RT2	0.0003

Split-Split pieces: RTxCT Quadratic components 43
Do we have <junk34>

Obs	_NAME_	_SOURCE_	_TYPE_	DF	SS	F	PROB
1	aw	ERROR	ERROR	642	21.9251	.	.
2	aw	RT	SS3	1	1.4140	41.404	0.00000
3	aw	CT	SS3	2	15.5020	226.961	0.00000
4	aw	RT*CT	SS3	2	0.3096	4.533	0.01109
5	aw	Quadratic CT	CONTRAST	1	0.3415	10.000	0.00164
6	aw	QuadraticCT@RT1	CONTRAST	1	0.0255	0.746	0.38808
7	aw	Quadratic@RT2	CONTRAST	1	0.4447	13.021	0.00033

Split-Split pieces: RTxCT Quadratic components 44
Do we have <splitsplit4>

Obs	DF	SS	_SOURCE_
1	16	0.2539	ERRORA
2	24	0.3853	ERRORB
3	528	9.3211	ERRORC
4	642	21.9251	ERROR
5	1	1.4140	RT
6	2	15.5020	CT
7	2	0.3096	RT*CT
8	1	0.3415	Quadra
9	1	0.0255	Quadra
10	1	0.4447	Quadra

Split-Split pieces: RT x CT Quadratic contrasts 45

(RT x QuadraticCT)SS = 0.1286417778

(RT x QuadraticCT)MS = 0.1286417778

F(RT x QuadraticCT) = 7.2870072819 p-value = 0.0071681696

Split-Split pieces: size, RT, time and Linear components 46

The GLM Procedure

Class Level Information

Class	Levels	Values
size	2	1 2
RT	2	1 2
time	3	1 2 3

Number of Observations Read 648
Number of Observations Used 648

Split-Split pieces: size, RT, time and Linear components 47

The GLM Procedure

Dependent Variable: aw

Source	DF	Sum of Squares	Mean Square	F Value
Model	11	7.40476120	0.67316011	13.49
Error	636	31.74598115	0.04991506	
Corrected Total	647	39.15074235		

Source	Pr > F
Model	<.0001
Error	
Corrected Total	

R-Square	Coeff Var	Root MSE	aw Mean
0.189135	39.31771	0.223417	0.568235

Source	DF	Type III SS	Mean Square	F Value
size	1	0.09709356	0.09709356	1.95
RT	1	1.41400139	1.41400139	28.33
size*RT	1	0.00329852	0.00329852	0.07
time	2	5.71563683	2.85781841	57.25
size*time	2	0.06168933	0.03084467	0.62
RT*time	2	0.03698878	0.01849439	0.37
size*RT*time	2	0.07605279	0.03802640	0.76

Source	Pr > F
size	0.1636
RT	<.0001
size*RT	0.7972
time	<.0001
size*time	0.5394
RT*time	0.6905
size*RT*time	0.4672

Contrast	DF	Contrast SS	Mean Square	F Value

Linear Time	1	5.65492934	5.65492934	113.29
LinT@size1	1	2.62659612	2.62659612	52.62

Split-Split pieces: size, RT, time and Linear components 48

The GLM Procedure

Dependent Variable: aw

Contrast	DF	Contrast SS	Mean Square	F Value
LinT@size2	1	3.03573356	3.03573356	60.82

Contrast	Pr > F
Linear Time	<.0001
LinT@size1	<.0001
LinT@size2	<.0001

Split-Split pieces: size, RT, time and Linear components 49

Do we have <junk35>

Obs	_NAME_	_SOURCE_	_TYPE_	DF	SS	F	PROB
1	aw	ERROR	ERROR	636	31.7460	.	.
2	aw	size	SS3	1	0.0971	1.945	0.16359
3	aw	RT	SS3	1	1.4140	28.328	0.00000
4	aw	size*RT	SS3	1	0.0033	0.066	0.79721
5	aw	time	SS3	2	5.7156	57.254	0.00000
6	aw	size*time	SS3	2	0.0617	0.618	0.53938
7	aw	RT*time	SS3	2	0.0370	0.371	0.69053
8	aw	size*RT*time	SS3	2	0.0761	0.762	0.46724
9	aw	Linear Time	CONTRAST	1	5.6549	113.291	0.00000
10	aw	LinT@size1	CONTRAST	1	2.6266	52.621	0.00000
11	aw	LinT@size2	CONTRAST	1	3.0357	60.818	0.00000

Split-Split pieces: size, RT, time and Linear components 50

Do we have <splitsplit5>

Obs	DF	SS	_SOURCE_
1	16	0.2539	ERRORA
2	24	0.3853	ERRORB
3	528	9.3211	ERRORC
4	636	31.7460	ERROR
5	1	0.0971	size
6	1	1.4140	RT
7	1	0.0033	size*R
8	2	5.7156	time
9	2	0.0617	size*t
10	2	0.0370	RT*tim
11	2	0.0761	size*R
12	1	5.6549	Linear
13	1	2.6266	LinT@s
14	1	3.0357	LinT@s

Split-Split pieces: size, RT, time and Linear contrasts 51

(Size)SS = 0.0970935556

(Size)MS = 0.0970935556

F(Size) = 5.4999352355 p-value = 0.0193864821

(SizexRT)SS = 0.0032985247

(SizexRT)MS = 0.0032985247

F(SizexRT) = 0.1868473358 p-value = 0.6657300869

(SizexTime)SS = 0.0616893333

(SizexTime)MS = 0.0308446667

F(SizexTime) = 1.747218629 p-value = 0.1752639341

(SizexRTxTime)SS = 0.0760527901

(SizexRTxTime)MS = 0.0380263951

F(SizexRTxTime) = 2.1540328695 p-value = 0.1170337681

(Size x LinearT)SS = 0.0074003333

(Size x LinearT)MS = 0.0074003333

F(Size x LinearT) = 0.4191972765 p-value = 0.5176192589

Split-Split pieces: size time quadratic components 52
The GLM Procedure

Class Level Information

Class	Levels	Values
size	2	1 2
time	3	1 2 3

Number of Observations Read 648
Number of Observations Used 648

Dependent Variable: aw

Source	DF	Sum of Squares	Mean Square	F Value
Model	5	5.87441972	1.17488394	22.67
Error	642	33.27632263	0.05183228	
Corrected Total	647	39.15074235		

Source	Pr > F
Model	<.0001
Error	
Corrected Total	

R-Square	Coeff Var	Root MSE	aw Mean
0.150046	40.06568	0.227667	0.568235

Source	DF	Type III SS	Mean Square	F Value
size	1	0.09709356	0.09709356	1.87
time	2	5.71563683	2.85781841	55.14
size*time	2	0.06168933	0.03084467	0.60

Source	Pr > F
size	0.1716
time	<.0001

size*time 0.5518

Contrast	DF	Contrast SS	Mean Square	F Value
Quadratic Time	1	0.06070748	0.06070748	1.17
QuadT@size1	1	0.00008963	0.00008963	0.00
QuadT@size2	1	0.11490685	0.11490685	2.22

Contrast	Pr > F
Quadratic Time	0.2796
QuadT@size1	0.9668
QuadT@size2	0.1370

Split-Split pieces: size time quadratic components 54
Do we have <junk36>

Obs	_NAME_	_SOURCE_	_TYPE_	DF	SS	F	PROB
1	aw	ERROR	ERROR	642	33.2763	.	.
2	aw	size	SS3	1	0.0971	1.8732	0.17158
3	aw	time	SS3	2	5.7156	55.1359	0.00000
4	aw	size*time	SS3	2	0.0617	0.5951	0.55182
5	aw	Quadratic Time	CONTRAST	1	0.0607	1.1712	0.27956
6	aw	QuadT@size1	CONTRAST	1	0.0001	0.0017	0.96684
7	aw	QuadT@size2	CONTRAST	1	0.1149	2.2169	0.13700

Split-Split pieces: size time quadratic components 55
Do we have <splitsplit6>

Obs	DF	SS	_SOURCE_
1	16	0.2539	ERRORA
2	24	0.3853	ERRORB
3	528	9.3211	ERRORC
4	642	33.2763	ERROR
5	1	0.0971	size
6	2	5.7156	time
7	2	0.0617	size*t
8	1	0.0607	Quadra
9	1	0.0001	QuadT@
10	1	0.1149	QuadT@

Split-Split pieces: Size Time Quadratic contrasts 56

(Size x QuadTime)SS = 0.054289

(Size x QuadTime)MS = 0.054289

F(Size x QuadTime) = 3.0752399816 p-value = 0.0800730646

Split-Split pieces: size CT Linear components 57

The GLM Procedure

Class Level Information

Class	Levels	Values
size	2	1 2
CT	3	1 2 3

Number of Observations Read 648
Number of Observations Used 648

Split-Split pieces: size CT Linear components 58

The GLM Procedure

Dependent Variable: aw

Source	DF	Sum of Squares	Mean Square	F Value
Model	5	15.65322001	3.13064400	85.54
Error	642	23.49752233	0.03660050	
Corrected Total	647	39.15074235		

Source	Pr > F
Model	<.0001
Error	
Corrected Total	

R-Square	Coeff Var	Root MSE	aw Mean
0.399819	33.66789	0.191313	0.568235

Source	DF	Type III SS	Mean Square	F Value
size	1	0.09709356	0.09709356	2.65
CT	2	15.50202237	7.75101119	211.77
size*CT	2	0.05410408	0.02705204	0.74

Source	Pr > F
size	0.1039
CT	<.0001
size*CT	0.4779

Contrast	DF	Contrast SS	Mean Square	F Value
Linear CT	1	15.16051200	15.16051200	414.22
LinCT@size1	1	8.43839004	8.43839004	230.55
LinCT@size2	1	6.76812604	6.76812604	184.92

Contrast	Pr > F
Linear CT	<.0001
LinCT@size1	<.0001
LinCT@size2	<.0001

Split-Split pieces: size CT Linear components 59
Do we have <junk37>

Obs	_NAME_	_SOURCE_	_TYPE_	DF	SS	F	PROB
1	aw	ERROR	ERROR	642	23.4975	.	.
2	aw	size	SS3	1	0.0971	2.653	0.10386
3	aw	CT	SS3	2	15.5020	211.773	0.00000
4	aw	size*CT	SS3	2	0.0541	0.739	0.47794
5	aw	Linear CT	CONTRAST	1	15.1605	414.216	0.00000
6	aw	LinCT@size1	CONTRAST	1	8.4384	230.554	0.00000
7	aw	LinCT@size2	CONTRAST	1	6.7681	184.919	0.00000

Split-Split pieces: size CT Linear components 60
Do we have <splitsplit7>

Obs	DF	SS	_SOURCE_
1	16	0.2539	ERRORA
2	24	0.3853	ERRORB
3	528	9.3211	ERRORC
4	642	23.4975	ERROR
5	1	0.0971	size

6	2	15.5020	CT
7	2	0.0541	size*C
8	1	15.1605	Linear
9	1	8.4384	LinCT@
10	1	6.7681	LinCT@

Split-Split pieces: size, CT Linear contrasts 61

(SizexCT)SS = 0.0541040833

(SizexCT)MS = 0.0270520417

F(SizexCT) = 1.5323826211 p-value = 0.2169794969

(Size x LinearCT)SS = 0.0460040833

(Size x LinearCT)MS = 0.0460040833

F(Size x LinearCT) = 2.6059348373 p-value = 0.1070617736

Split-Split pieces: size CT quadratic components 62

The GLM Procedure

Class Level Information

Class	Levels	Values
size	2	1 2
CT	3	1 2 3

Number of Observations Read 648
Number of Observations Used 648

Split-Split pieces: size CT quadratic components 63

The GLM Procedure

Dependent Variable: aw

Source	DF	Sum of Squares	Mean Square	F Value
Model	5	15.65322001	3.13064400	85.54
Error	642	23.49752233	0.03660050	
Corrected Total	647	39.15074235		

Source	Pr > F
Model	<.0001
Error	
Corrected Total	

R-Square	Coeff Var	Root MSE	aw Mean
0.399819	33.66789	0.191313	0.568235

Source	DF	Type III SS	Mean Square	F Value
size	1	0.09709356	0.09709356	2.65
CT	2	15.50202237	7.75101119	211.77
size*CT	2	0.05410408	0.02705204	0.74

Source	Pr > F

size 0.1039
CT <.0001
size*CT 0.4779

Contrast	DF	Contrast SS	Mean Square	F Value
Quadratic CT	1	0.34151037	0.34151037	9.33
QuadCT@size1	1	0.12221019	0.12221019	3.34
QuadCT@size2	1	0.22740019	0.22740019	6.21

Contrast	Pr > F
Quadratic CT	0.0023
QuadCT@size1	0.0681
QuadCT@size2	0.0129

Split-Split pieces: size CT quadratic components 64
Do we have <junk38>

Obs	_NAME_	_SOURCE_	_TYPE_	DF	SS	F	PROB
1	aw	ERROR	ERROR	642	23.4975	.	.
2	aw	size	SS3	1	0.0971	2.653	0.10386
3	aw	CT	SS3	2	15.5020	211.773	0.00000
4	aw	size*CT	SS3	2	0.0541	0.739	0.47794
5	aw	Quadratic CT	CONTRAST	1	0.3415	9.331	0.00235
6	aw	QuadCT@size1	CONTRAST	1	0.1222	3.339	0.06812
7	aw	QuadCT@size2	CONTRAST	1	0.2274	6.213	0.01293

Split-Split pieces: size CT quadratic components 65
Do we have <splitsplit8>

Obs	DF	SS	_SOURCE_
1	16	0.2539	ERRORA
2	24	0.3853	ERRORB
3	528	9.3211	ERRORC
4	642	23.4975	ERROR
5	1	0.0971	size
6	2	15.5020	CT
7	2	0.0541	size*C
8	1	0.3415	Quadra
9	1	0.1222	QuadCT
10	1	0.2274	QuadCT

Split-Split pieces: Size CT Quadratic contrasts 66

(Size x Quad CT)SS = 0.0081

(Size x Quad CT)MS = 0.0081

F(Size x Quad CT) = 0.4588304049 p-value = 0.4984677746

Split-Split pieces: abrade CT Linear components 67

The GLM Procedure

Class Level Information

Class	Levels	Values
abrade	2	1 2
CT	3	1 2 3

Number of Observations Read 648
Number of Observations Used 648

Split-Split pieces: abrade CT Linear components 68
The GLM Procedure

Dependent Variable: aw

Source	DF	Sum of Squares	Mean Square	F Value
Model	5	15.86203596	3.17240719	87.45
Error	642	23.28870639	0.03627524	
Corrected Total	647	39.15074235		

Source	Pr > F
Model	<.0001
Error	
Corrected Total	

R-Square	Coeff Var	Root MSE	aw Mean
0.405153	33.51796	0.190461	0.568235

Source	DF	Type III SS	Mean Square	F Value
abrade	1	0.35504356	0.35504356	9.79
CT	2	15.50202237	7.75101119	213.67
abrade*CT	2	0.00497003	0.00248501	0.07

Source	Pr > F
abrade	0.0018
CT	<.0001
abrade*CT	0.9338

Contrast	DF	Contrast SS	Mean Square	F Value
Linear CT	1	15.16051200	15.16051200	417.93
LinCT@abrade1	1	7.77026400	7.77026400	214.20
LinCT@abrade2	1	7.39260000	7.39260000	203.79

Contrast	Pr > F
Linear CT	<.0001
LinCT@abrade1	<.0001
LinCT@abrade2	<.0001

Split-Split pieces: abrade CT Linear components 69
Do we have <junk39>

Obs	_NAME_	_SOURCE_	_TYPE_	DF	SS	F	PROB
1	aw	ERROR	ERROR	642	23.2887	.	.
2	aw	abrade	SS3	1	0.3550	9.787	0.00184
3	aw	CT	SS3	2	15.5020	213.672	0.00000
4	aw	abrade*CT	SS3	2	0.0050	0.069	0.93380
5	aw	Linear CT	CONTRAST	1	15.1605	417.930	0.00000
6	aw	LinCT@abrade1	CONTRAST	1	7.7703	214.203	0.00000
7	aw	LinCT@abrade2	CONTRAST	1	7.3926	203.792	0.00000

Split-Split pieces: abrade CT Linear components 70
Do we have <splitsplit9>

Obs	DF	SS	_SOURCE_
1	16	0.2539	ERRORA
2	24	0.3853	ERRORB
3	528	9.3211	ERRORC

4	642	23.2887	ERROR
5	1	0.3550	abrade
6	2	15.5020	CT
7	2	0.0050	abrade
8	1	15.1605	Linear
9	1	7.7703	LinCT@
10	1	7.3926	LinCT@

Split-Split pieces: Abrade, CT Linear contrasts 71

(Abrade)SS = 0.3550435556

(Abrade)MS = 0.3550435556

F(Abrade) = 20.111701031 p-value = 8.9681446E-6

(AbradexCT)SS = 0.0049700278

(AbradexCT)MS = 0.0024850139

F(AbradexCT) = 0.1407654233 p-value = 0.8687256525

(Abrade x LinearCT)SS = 0.002352

(Abrade x LinearCT)MS = 0.002352

F(Abrade x LinearCT) = 0.1332307546 p-value = 0.7152516795

Split-Split pieces: Abrade CT quadratic components 72

The GLM Procedure

Class Level Information

Class	Levels	Values
abrade	2	1 2
CT	3	1 2 3

Number of Observations Read	648
Number of Observations Used	648

Split-Split pieces: Abrade CT quadratic components 73

The GLM Procedure

Dependent Variable: aw

Source	DF	Sum of Squares	Mean Square	F Value
Model	5	15.86203596	3.17240719	87.45
Error	642	23.28870639	0.03627524	
Corrected Total	647	39.15074235		

Source	Pr > F
Model	<.0001
Error	
Corrected Total	

R-Square	Coeff Var	Root MSE	aw Mean
0.405153	33.51796	0.190461	0.568235

Source	DF	Type III SS	Mean Square	F Value
abrade	1	0.35504356	0.35504356	9.79
CT	2	15.50202237	7.75101119	213.67
abrade*CT	2	0.00497003	0.00248501	0.07

Source	Pr > F
abrade	0.0018
CT	<.0001
abrade*CT	0.9338

Contrast	DF	Contrast SS	Mean Square	F Value
Quadratic CT	1	0.34151037	0.34151037	9.41
QuadCT@abrade1	1	0.14216297	0.14216297	3.92
QuadCT@abrade2	1	0.20196543	0.20196543	5.57

Contrast	Pr > F
Quadratic CT	0.0022
QuadCT@abrade1	0.0482
QuadCT@abrade2	0.0186

Split-Split pieces: Abrade CT quadratic components 74
Do we have <junk310>

Obs	_NAME_	_SOURCE_	_TYPE_	DF	SS	F	PROB
1	aw	ERROR	ERROR	642	23.2887	.	.
2	aw	abrade	SS3	1	0.3550	9.787	0.00184
3	aw	CT	SS3	2	15.5020	213.672	0.00000
4	aw	abrade*CT	SS3	2	0.0050	0.069	0.93380
5	aw	Quadratic CT	CONTRAST	1	0.3415	9.414	0.00224
6	aw	QuadCT@abrade1	CONTRAST	1	0.1422	3.919	0.04817
7	aw	QuadCT@abrade2	CONTRAST	1	0.2020	5.568	0.01859

Split-Split pieces: Abrade CT quadratic components 75
Do we have <splitsplit10>

Obs	DF	SS	_SOURCE_
1	16	0.2539	ERRORA
2	24	0.3853	ERRORB
3	528	9.3211	ERRORC
4	642	23.2887	ERROR
5	1	0.3550	abrade
6	2	15.5020	CT
7	2	0.0050	abrade
8	1	0.3415	Quadra
9	1	0.1422	QuadCT
10	1	0.2020	QuadCT

Split-Split pieces: abrade CT Quadratic contrasts 76

(abrade x Quad CT)SS = 0.0026180278

(abrade x Quad CT)MS = 0.0026180278

F(abrade x Quad CT) = 0.148300092 p-value = 0.700320252

Split-Split pieces: abrade time Linear components 77
06:58 Wednesday, August 3, 2005

The GLM Procedure

Class Level Information

Class	Levels	Values

abrade 2 1 2

time 3 1 2 3

Number of Observations Read 648
Number of Observations Used 648

Split-Split pieces: abrade time Linear components 78

The GLM Procedure

Dependent Variable: aw

Source	DF	Sum of Squares	Mean Square	F Value
Model	5	6.32123553	1.26424711	24.72
Error	642	32.82950681	0.05113630	
Corrected Total	647	39.15074235		

Source	Pr > F
Model	<.0001
Error	
Corrected Total	

R-Square	Coeff Var	Root MSE	aw Mean
0.161459	39.79578	0.226133	0.568235

Source	DF	Type III SS	Mean Square	F Value
abrade	1	0.35504356	0.35504356	6.94
time	2	5.71563683	2.85781841	55.89
abrade*time	2	0.25055515	0.12527757	2.45

Source	Pr > F
abrade	0.0086
time	<.0001
abrade*time	0.0871

Contrast	DF	Contrast SS	Mean Square	F Value
Linear Time	1	5.65492934	5.65492934	110.59
LinT@abrade1	1	2.41808017	2.41808017	47.29
LinT@abrade2	1	3.26884807	3.26884807	63.92

Contrast	Pr > F
Linear Time	<.0001
LinT@abrade1	<.0001
LinT@abrade2	<.0001

Split-Split pieces: abrade time Linear components 79
Do we have <junk311>

Obs	_NAME_	_SOURCE_	_TYPE_	DF	SS	F	PROB
1	aw	ERROR	ERROR	642	32.8295	.	.
2	aw	abrade	SS3	1	0.3550	6.943	0.008617
3	aw	time	SS3	2	5.7156	55.886	0.000000
4	aw	abrade*time	SS3	2	0.2506	2.450	0.087111
5	aw	Linear Time	CONTRAST	1	5.6549	110.585	0.000000
6	aw	LinT@abrade1	CONTRAST	1	2.4181	47.287	0.000000

7 aw LinT@abrade2 CONTRAST 1 3.2688 63.924 0.000000

Split-Split pieces: abrade time Linear components 80
Do we have <splitsplit11>

Obs	DF	SS	_SOURCE_
1	16	0.2539	ERRORA
2	24	0.3853	ERRORB
3	528	9.3211	ERRORC
4	642	32.8295	ERROR
5	1	0.3550	abrade
6	2	5.7156	time
7	2	0.2506	abrade
8	1	5.6549	Linear
9	1	2.4181	LinT@a
10	1	3.2688	LinT@a

Split-Split pieces: Abrade, time Linear contrasts 81

(AbradexTime)SS = 0.2505551481

(AbradexTime)MS = 0.1252775741

F(AbradexTime) = 7.0964395106 p-value = 0.0009093894

(Abrade x LinearTime)SS = 0.0319988981

(Abrade x LinearTime)MS = 0.0319988981

F(Abrade x LinearTime) = 1.8126009127 p-value = 0.17877423

Split-Split pieces: Abrade time quadratic components 82

The GLM Procedure

Class Level Information

Class	Levels	Values
abrade	2	1 2
time	3	1 2 3

Number of Observations Read 648
Number of Observations Used 648

Split-Split pieces: Abrade time quadratic components 83

The GLM Procedure

Dependent Variable: aw

Source	DF	Sum of Squares	Mean Square	F Value
Model	5	6.32123553	1.26424711	24.72
Error	642	32.82950681	0.05113630	
Corrected Total	647	39.15074235		

Source	Pr > F
Model	<.0001
Error	
Corrected Total	

R-Square Coeff Var Root MSE aw Mean

0.161459 39.79578 0.226133 0.568235

Source	DF	Type III SS	Mean Square	F Value
abrade	1	0.35504356	0.35504356	6.94
time	2	5.71563683	2.85781841	55.89
abrade*time	2	0.25055515	0.12527757	2.45

Source	Pr > F
abrade	0.0086
time	<.0001
abrade*time	0.0871

Contrast	DF	Contrast SS	Mean Square	F Value
Quadratic Time	1	0.06070748	0.06070748	1.19
QuadT@abrade1	1	0.25481867	0.25481867	4.98
QuadT@abrade2	1	0.02444506	0.02444506	0.48

Contrast	Pr > F
Quadratic Time	0.2763
QuadT@abrade1	0.0259
QuadT@abrade2	0.4896

Split-Split pieces: Abrade time quadratic components 84
Do we have <junk312>

Obs	_NAME_	_SOURCE_	_TYPE_	DF	SS	F	PROB
1	aw	ERROR	ERROR	642	32.8295	.	.
2	aw	abrade	SS3	1	0.3550	6.9431	0.00862
3	aw	time	SS3	2	5.7156	55.8863	0.00000
4	aw	abrade*time	SS3	2	0.2506	2.4499	0.08711
5	aw	Quadratic Time	CONTRAST	1	0.0607	1.1872	0.27631
6	aw	QuadT@abrade1	CONTRAST	1	0.2548	4.9831	0.02594
7	aw	QuadT@abrade2	CONTRAST	1	0.0244	0.4780	0.48956

Split-Split pieces: Abrade time quadratic components 85
Do we have <splitsplit12>

Obs	DF	SS	_SOURCE_
1	16	0.2539	ERRORA
2	24	0.3853	ERRORB
3	528	9.3211	ERRORC
4	642	32.8295	ERROR
5	1	0.3550	abrade
6	2	5.7156	time
7	2	0.2506	abrade
8	1	0.0607	Quadra
9	1	0.2548	QuadT@
10	1	0.0244	QuadT@

Split-Split pieces: abrade time Quadratic contrasts 86

(abrade x Quad Time)SS = 0.21855625

(abrade x Quad Time)MS = 0.21855625

F(abrade x Quad Time) = 12.380278108 p-value = 0.0004713308

Split-Split pieces: not previously covered 87
The GLM Procedure

Class Level Information

Class	Levels	Values
CT	3	1 2 3
RT	2	1 2
time	3	1 2 3
size	2	1 2
abrade	2	1 2

Number of Observations Read 648
Number of Observations Used 648

Split-Split pieces: not previously covered 88

The GLM Procedure

Dependent Variable: aw

Source	DF	Sum of Squares	Mean Square	F Value
Model	71	27.92620923	0.39332689	20.18
Error	576	11.22453311	0.01948704	
Corrected Total	647	39.15074235		

Source	Pr > F
Model	<.0001
Error	
Corrected Total	

R-Square	Coeff Var	Root MSE	aw Mean
0.713300	24.56661	0.139596	0.568235

Source	DF	Type III SS	Mean Square	F Value
CT*RT*time	4	0.80102244	0.20025561	10.28
RT*size	1	0.00329852	0.00329852	0.17
CT*time*size	4	0.07967669	0.01991917	1.02
RT*time*size	2	0.07605279	0.03802640	1.95
CT*RT*size	2	0.13953604	0.06976802	3.58
CT*RT*time*size	4	0.32344759	0.08086190	4.15
RT*abrade	1	0.11418890	0.11418890	5.86
RT*time*abrade	2	0.10348083	0.05174041	2.66
CT*time*abrade	4	0.29682616	0.07420654	3.81

Source	Pr > F
CT*RT*time	<.0001
RT*size	0.6809
CT*time*size	0.3951
RT*time*size	0.1430
CT*RT*size	0.0285
CT*RT*time*size	0.0025
RT*abrade	0.0158
RT*time*abrade	0.0712
CT*time*abrade	0.0046

Split-Split pieces: not previously covered 89

The GLM Procedure

Dependent Variable: aw

Source	DF	Type III SS	Mean Square	F Value
CT*RT*abrade	2	0.07668910	0.03834455	1.97
CT*RT*time*abrade	4	0.41036990	0.10259248	5.26
size*abrade	1	0.05644800	0.05644800	2.90
time*size*abrade	2	0.02543748	0.01271874	0.65
RT*size*abrade	1	0.05102238	0.05102238	2.62
RT*time*size*abrade	2	0.38122820	0.19061410	9.78
CT*size*abrade	2	0.01573879	0.00786939	0.40
CT*time*size*abrade	4	0.31567195	0.07891799	4.05
CT*RT*size*abrade	2	0.00281363	0.00140682	0.07
CT*RT*time*size*abra	4	0.10269640	0.02567410	1.32

Source	Pr > F
CT*RT*abrade	0.1407
CT*RT*time*abrade	0.0004
size*abrade	0.0893
time*size*abrade	0.5210
RT*size*abrade	0.1062
RT*time*size*abrade	<.0001
CT*size*abrade	0.6679
CT*time*size*abrade	0.0030
CT*RT*size*abrade	0.9304
CT*RT*time*size*abra	0.2621

Split-Split pieces: not previously covered 90
Do we have <junk313>

Obs	_NAME_	_SOURCE_	_TYPE_	DF	SS	F	PROB
1	aw	ERROR	ERROR	576	11.2245	.	.
2	aw	CT*RT*time	SS3	4	0.8010	10.2763	0.00000
3	aw	RT*size	SS3	1	0.0033	0.1693	0.68092
4	aw	CT*time*size	SS3	4	0.0797	1.0222	0.39511
5	aw	RT*time*size	SS3	2	0.0761	1.9514	0.14302
6	aw	CT*RT*size	SS3	2	0.1395	3.5802	0.02849
7	aw	CT*RT*time*size	SS3	4	0.3234	4.1495	0.00254
8	aw	RT*abrade	SS3	1	0.1142	5.8597	0.01580
9	aw	RT*time*abrade	SS3	2	0.1035	2.6551	0.07115
10	aw	CT*time*abrade	SS3	4	0.2968	3.8080	0.00458
11	aw	CT*RT*abrade	SS3	2	0.0767	1.9677	0.14072
12	aw	CT*RT*time*abrade	SS3	4	0.4104	5.2647	0.00036
13	aw	size*abrade	SS3	1	0.0564	2.8967	0.08930
14	aw	time*size*abrade	SS3	2	0.0254	0.6527	0.52103
15	aw	RT*size*abrade	SS3	1	0.0510	2.6183	0.10619
16	aw	RT*time*size*abrade	SS3	2	0.3812	9.7816	0.00007
17	aw	CT*size*abrade	SS3	2	0.0157	0.4038	0.66795
18	aw	CT*time*size*abrade	SS3	4	0.3157	4.0498	0.00301
19	aw	CT*RT*size*abrade	SS3	2	0.0028	0.0722	0.93036
20	aw	CT*RT*time*size*abra	SS3	4	0.1027	1.3175	0.26211

Split-Split pieces: not previously covered 91
Do we have <splitsplit13>

Obs	_SOURCE_	DF	SS
1	ERROR	576	11.2245
2	CT*RT*time	4	0.8010
3	RT*size	1	0.0033
4	CT*time*size	4	0.0797
5	RT*time*size	2	0.0761
6	CT*RT*size	2	0.1395
7	CT*RT*time*size	4	0.3234
8	RT*abrade	1	0.1142
9	RT*time*abrade	2	0.1035

10	CT*time*abrade	4	0.2968
11	CT*RT*abrade	2	0.0767
12	CT*RT*time*abrade	4	0.4104
13	size*abrade	1	0.0564
14	time*size*abrade	2	0.0254
15	RT*size*abrade	1	0.0510
16	RT*time*size*abrade	2	0.3812
17	CT*size*abrade	2	0.0157
18	CT*time*size*abrade	4	0.3157
19	CT*RT*size*abrade	2	0.0028
20	CT*RT*time*size*abra	4	0.1027
21	ERRORA	16	0.2539
22	ERRORB	24	0.3853
23	ERRORC	528	9.3211

Split-Split pieces: not previously covered 92
The rest of the F and p values

Obs	_SOURCE_	DF	SS	MS	F	P
1	ERROR	576	11.2245	0.01949	1.1039	0.12367
2	CT*RT*time	4	0.8010	0.20026	11.3436	0.00000
3	RT*size	1	0.0033	0.00330	0.1868	0.66573
4	CT*time*size	4	0.0797	0.01992	1.1283	0.34223
5	RT*time*size	2	0.0761	0.03803	2.1540	0.11703
6	CT*RT*size	2	0.1395	0.06977	3.9521	0.01979
7	CT*RT*time*size	4	0.3234	0.08086	4.5805	0.00121
8	RT*abrade	1	0.1142	0.11419	6.4683	0.01127
9	RT*time*abrade	2	0.1035	0.05174	2.9309	0.05422
10	CT*time*abrade	4	0.2968	0.07421	4.2035	0.00233
11	CT*RT*abrade	2	0.0767	0.03834	2.1721	0.11496
12	CT*RT*time*abrade	4	0.4104	0.10259	5.8114	0.00014
13	size*abrade	1	0.0564	0.05645	3.1975	0.07432
14	time*size*abrade	2	0.0254	0.01272	0.7205	0.48700
15	RT*size*abrade	1	0.0510	0.05102	2.8902	0.08971
16	RT*time*size*abrade	2	0.3812	0.19061	10.7975	0.00003
17	CT*size*abrade	2	0.0157	0.00787	0.4458	0.64057
18	CT*time*size*abrade	4	0.3157	0.07892	4.4704	0.00146
19	CT*RT*size*abrade	2	0.0028	0.00141	0.0797	0.92341
20	CT*RT*time*size*abra	4	0.1027	0.02567	1.4543	0.21488
21	ERRORA	16	0.2539	0.01587	0.8990	0.57055
22	ERRORB	24	0.3853	0.01605	0.9094	0.58948
23	ERRORC	528	9.3211	0.01765	1.0000	0.5000

PROGRAM FOR MOISTURE CONTENT (FRESH)

```
/* Split-Split Plot Design... */

dm 'output; clear; log; clear';
options ls=72 ps=55 pageno=1 formdlim=' ';
title 'Split-Split Plot Statistical Analysis of Fresh Blueberry Final MC';
title1 'Batch Vacuum-belt Drying Analysis 23 May 2010';
data one;
do time=1 to 3;
      do RT=1 to 2;
            do CT=1 to 3;
                  do size=1 to 2;
                        do abrade=1 to 2;
                              do rep=1 to 9;

input mc@@;
output;
end;
end;
end;
end;
```

```
end;
end;


cards;
0.560 0.466 0.481 0.535 0.528 0.595 0.622 0.315 0.445 0.512 0.614 0.365

0.330 0.472 0.449 0.420 0.393 0.341 0.622 0.610 0.640 0.604 0.597 0.628
0.605 0.538 0.581 0.631 0.667 0.589 0.265 0.343 0.470 0.376 0.330 0.260
0.570 0.360 0.491 0.484 0.451 0.481 0.062 0.106 0.124 0.175 0.357 0.330
0.246 0.168 0.218 0.468 0.366 0.376 0.300 0.287 0.094 0.435 0.557 0.546
0.246 0.364 0.326 0.283 0.277 0.066 0.452 0.070 0.284 0.185 0.240 0.177
0.085 0.172 0.220 0.310 0.093 0.300 0.223 0.293 0.380 0.011 0.000 0.015
0.093 0.012 0.019 0.000 0.000 0.000 0.402 0.341 0.168 0.170 0.233 0.135
0.251 0.218 0.218 0.046 0.190 0.215 0.272 0.350 0.283 0.005 0.035 0.008
0.560 0.341 0.327 0.625 0.595 0.569 0.226 0.355 0.192 0.501 0.461 0.255
0.388 0.346 0.523 0.560 0.481 0.398 0.514 0.622 0.588 0.556 0.543 0.607
0.378 0.576 0.525 0.296 0.379 0.396 0.398 0.324 0.129 0.320 0.320 0.320
0.445 0.226 0.260 0.040 0.115 0.000 0.008 0.019 0.045 0.470 0.379 0.301
0.315 0.144 0.192 0.005 0.115 0.013 0.455 0.389 0.398 0.383 0.389 0.238
0.138 0.076 0.154 0.045 0.238 0.277 0.147 0.218 0.092 0.169 0.169 0.169
0.009 0.000 0.000 0.010 0.003 0.000 0.006 0.006 0.007 0.002 0.000 0.000
0.093 0.151 0.077 0.015 0.010 0.005 0.220 0.148 0.076 0.027 0.042 0.039
0.092 0.092 0.092 0.251 0.249 0.076 0.124 0.109 0.109 0.000 0.000 0.000
0.487 0.433 0.496 0.372 0.508 0.341 0.245 0.429 0.112 0.536 0.507 0.437
0.641 0.523 0.486 0.652 0.484 0.515 0.425 0.713 0.476 0.412 0.406 0.208
0.578 0.605 0.520 0.330 0.367 0.212 0.209 0.411 0.228 0.153 0.331 0.254
0.021 0.209 0.090 0.227 0.067 0.027 0.392 0.342 0.330 0.098 0.290 0.249
0.030 0.289 0.055 0.025 0.038 0.022 0.166 0.173 0.374 0.187 0.249 0.225
0.176 0.039 0.188 0.225 0.369 0.247 0.036 0.129 0.241 0.027 0.099 0.104
0.025 0.038 0.002 0.003 0.074 0.009 0.019 0.025 0.023 0.015 0.010 0.016
0.244 0.182 0.072 0.014 0.012 0.013 0.002 0.001 0.006 0.008 0.018 0.010
0.079 0.033 0.034 0.000 0.000 0.002 0.009 0.005 0.009 0.006 0.000 0.018
0.321 0.601 0.293 0.227 0.257 0.247 0.076 0.200 0.175 0.273 0.211 0.399
0.297 0.300 0.475 0.303 0.136 0.228 0.527 0.322 0.239 0.157 0.285 0.265
0.241 0.157 0.101 0.472 0.301 0.218 0.349 0.205 0.485 0.394 0.501 0.416
0.167 0.231 0.463 0.015 0.035 0.010 0.012 0.055 0.013 0.093 0.039 0.147
0.018 0.024 0.015 0.000 0.006 0.019 0.053 0.010 0.009 0.196 0.190 0.079
0.003 0.005 0.002 0.095 0.059 0.008 0.057 0.229 0.012 0.019 0.000 0.035
0.077 0.004 0.007 0.004 0.004 0.007 0.004 0.005 0.010 0.004 0.005 0.000
0.008 0.007 0.009 0.023 0.061 0.055 0.037 0.063 0.063 0.045 0.006 0.023
0.000 0.090 0.074 0.005 0.000 0.014 0.173 0.235 0.248 0.000 0.000 0.006 0.211
0.220 0.124 0.385 0.369 0.321 0.191 0.499 0.129 0.254 0.232 0.502
0.067 0.052 0.042 0.109 0.019 0.125 0.540 0.478 0.571 0.532 0.422 0.529
0.281 0.102 0.061 0.627 0.333 0.373 0.238 0.308 0.463 0.526 0.564 0.637
0.279 0.306 0.366 0.010 0.011 0.033 0.128 0.128 0.128 0.026 0.008 0.006
0.047 0.017 0.156 0.014 0.017 0.042 0.209 0.142 0.456 0.121 0.227 0.220
0.060 0.066 0.031 0.012 0.032 0.065 0.068 0.070 0.179 0.030 0.050 0.024
0.069 0.028 0.045 0.006 0.054 0.007 0.000 0.000 0.000 0.013 0.033 0.052
0.000 0.000 0.000 0.000 0.000 0.015 0.000 0.000 0.025 0.008 0.043 0.006
0.004 0.005 0.040 0.005 0.011 0.013 0.007 0.012 0.010 0.000 0.013 0.007 0.231
0.255 0.398 0.228 0.242 0.215 0.010 0.001 0.010 0.100 0.115 0.295 0.016 0.027
0.129 0.036 0.021 0.149 0.380 0.438 0.414 0.316 0.061 0.172
0.076 0.049 0.111 0.016 0.011 0.034 0.007 0.014 0.017 0.028 0.038 0.032
0.107 0.124 0.111 0.013 0.009 0.026 0.001 0.000 0.000 0.063 0.030 0.032
0.259 0.099 0.052 0.000 0.000 0.000 0.062 0.090 0.073 0.007 0.027 0.033
0.017 0.141 0.070 0.013 0.022 0.012 0.087 0.047 0.163 0.000 0.000 0.011
```

```
0.008 0.013 0.017 0.008 0.004 0.007 0.013 0.012 0.014 0.005 0.000 0.001
0.009 0.014 0.017 0.005 0.006 0.004 0.100 0.115 0.295 0.187 0.100 0.230
0.000 0.000 0.000 0.000 0.001 0.007 0.032 0.001 0.089 0.000 0.000 0.000
;
/*proc print; run; /*Yes*/
proc glm data=one outstat=junk1;
class rep abrade size CT RT time;
model mc=time|RT|CT|size|abrade|rep /ss3;
means time RT CT size abrade;
run;

data two;
set junk1;
keep _SOURCE_ DF SS;
output;
proc print data=two;
title 'RT qual, Time quantitative; SOURCE, DF & SS data only....contrasts';
run;


/*To find Error a/b/c SS and DFs */
data two2; set two;
proc iml;
use two2;
read all var {DF SS} into P;
ER=J(3,2,0);
/*Error terms, col1=df, col2=SS; row1-2-3=Error(a)-(b)-(c) */
ER[1,1]=P[34,1]; ER[1,2]=P[34,2];
ER[2,1]=P[35,1]+P[36,1]; ER[2,2]=P[35,2]+P[36,2];
EC=J(28,2,0); /*To collect all 28 rep*effects for Error(c) */
EC[1:28,1:2]=P[37:64,1:2];
ER[3,1]=EC[+,1]; ER[3,2]=EC[+,2]; /*sum over rows of EC */
print ER EC; /*OK*/
varnames={DF SS};
create outER from ER (|colname=varnames|);
append from ER;
run;

data ER; set outER;      /*This ER dataset has ErrorSSa/b/c */
if _N_ = 1 then _SOURCE_ = 'ERRORA';
if _N_ = 2 then _SOURCE_ = 'ERRORB';
if _N_ = 3 then _SOURCE_ = 'ERRORC';
output; run;
data two2;
set two ER;
proc print data=two2;
title "Is this two2"; run; /*OK*/


/*WHOLE PLOTS part */
proc glm data=one outstat=junk1;
title1 "Whole Plot pieces: Time and reps";
class time rep;
model mc=time|rep /ss3;
contrast 'Linear Time' time -1 0 1;
contrast 'Quad Time' time -1 2 -1;
test h=time e=time*rep;
```

```
test h=rep e=time*rep;
run;

proc print data=junk1;
title2 "Do we have <junk1>"; run; /*Yes*/

data whole;
set junk1 end=last;
keep _SOURCE_ DF SS;
title2 "Time contrasts";
retain div dfE LinT QuadT 0;
if _N_ = 4 then dfE=DF; else dfE=dfE+0;     /*This is Error(a) */
if _N_ = 4 then div=SS/DF; else div=div+0;
if _N_ = 5 then LinT=SS; else LinT=LinT+0;
if _N_ = 6 then QuadT=SS; else QuadT=QuadT+0;
if last then do;
  /*to find F and p-values for Lin/Quad Time */
  LinTMS=LinT; QuadTMS=QuadT; /* df=1 here */
  FLinT=LinTMS/div; pLinT=1-probf(FLinT,1,dfE);
  FQuadT=QuadTMS/div; pQuadT=1-probf(FQuadT,1,dfE);
  file print;
  put ///'     (LinearTime)SS = ' LinT;
  put / '      (LinearTime)MS = ' LinTMS;
  put /'      F(LinT) = ' FLinT 'p-value = ' pLinT;
  put ///'     (QuadTime)SS = ' QuadT;
  put / '      (QuadTime)MS = ' QuadTMS;
  put /'      F(QuadT) = ' FQuadT 'p-value = ' pQuadT;
  output;
end;
run;

/*SPLIT-PLOT part */
proc glm data=one outstat=junk2;
title1 "Split plot pieces: RT, RTxTime";
class RT time;
model mc=RT|time/ss3;
contrast "Linear Time" time -1 0 1;
contrast "LinTime@RT1" time -1 0 1 RT*time -1 0 1;
contrast "LinTime@RT2" time -1 0 1 RT*time 0 0 0 -1 0 1;
run;

/*proc print data=junk2;
title "Do we have <junk2>"; run; /*Yes*/

/*Find RT x Linear Time Contrast*/
data split1;
set ER junk2;  /*merge Error a/b/c dataset with junk2 */
keep _SOURCE_ DF SS;
proc print;
title2 "Do we have <split1>"; run; /*Yes*/
run;
title2 ' ';
data split1; set split1 end=last;
title1 "Split Plot pieces: RT, RT*Time and Linear contrasts";
retain div dfE dfRT dfRTtime RT RTtime RTLinT 0;
if _N_ = 2 then dfE=DF; else dfE=dfE+0;     /*This is Error(b) */
if _N_ = 2 then div=SS/DF; else div=div+0;
```

```
if _N_ = 5 then dfRT=DF; else dfRT=dfRT+0;  /*df for RTxLinTime*/
if _N_ = 7 then dfRTtime=DF; else dfRTtime=dfRTtime+0; /*df for RTxTime */
if _N_ = 5 then RT=SS; else RT=RT+0; /* RT SS */
if _N_ = 7 then RTtime=SS; else RTtime=RTtime+0; /*RTxTime SS */
if _N_ < 8 then SS=0;
else if _N_ = 8 then SS=-SS;
RTLinT=RTLinT+SS;  /* RtxLinTime SS */
if last then do;
  /*to find F and p-values for RT, RTxTime, RTxLinTime */
  RTMS=RT/dfRT;    /* RT MS */
  FRT=RTMS/div; pRT=1-probf(FRT,dfRT,dfE); /* RT F-, p- values*/
  RTtimeMS=RTtime/dfRTtime;
  FRTtime=RTtimeMS/div; pRTtime=1-probf(FRTtime,dfRTtime,dfE);
  RTLinTMS=RTLinT/dfRT;
  FRTLinT=RTLinTMS/div; pRTLinT=1-probf(FRTLinT,dfRT,dfE);
  file print;
  put ///'     (RT)SS = ' RT;
  put / '      (RT)MS = ' RTMS;
  put /'      F(RT) = ' FRT 'p-value = ' pRT;
  put ///'     (RTxTime)SS = ' RTtime;
  put / '      (RTxTime)MS = ' RTtimeMS;
  put /'      F(RTxTime) = ' FRTtime 'p-value = ' pRTtime;
  put ///'     (RT x LinearTime)SS = ' RTLinT;
  put / '      (RT x LinearTime)MS = ' RTLinTMS;
  put /'      F(RT x LinT) = ' FRTLinT 'p-value = ' pRTLinT;
  output;
end;
run;
/*Do RT x Quad Time contrast*/
proc glm data=one outstat=junk22;
title1 "Split Plot pieces: RT by Quad Time contrasts";
class RT time;
model mc=RT|time/ss3;
contrast "Quad Time" time -1 2 -1;
contrast "QuadTime@RT1" time -1 2 -1 RT*time -1 2 -1;
contrast "QuadTime@RT2" time -1 2 -1 RT*time 0 0 0 -1 2 -1;
run;

/*proc print data=junk22;
title2 "Do we have <junk22>"; run; /*Yes*/

/*Find RT x Quad Time Contrast*/
data split2;
set ER junk22;  /*merge Error a/b/c dataset with junk22 */
keep _SOURCE_ DF SS;
proc print;
title2 "Do we have <split2>"; run; /*Yes*/
run; title2 ' ';
data split2; set split2 end=last;
title1 "Split Plot pieces: RT by Quad Time contrast";
retain div dfE dfRT RTQuadT 0;
if _N_ = 2 then dfE=DF; else dfE=dfE+0;     /*This is Error(b) */
if _N_ = 2 then div=SS/DF; else div=div+0;
if _N_ = 5 then dfRT=DF; else dfRT=dfRT+0;  /*df for RTxQuadTime*/
if _N_ < 8 then SS=0;
else if _N_ = 8 then SS=-SS;
RTQuadT=RTQuadT+SS;
```

```
if last then do;
  /*to find F and p-values for RTxQuadTime */
  RTQuadTMS=RTQuadT/dfRT;
  FRTQuadT=RTQuadTMS/div; pRTQuadT=1-probf(FRTQuadT,dfRT,dfE);
  file print;
  put ///'     (RT x QuadTime)SS = ' RTQuadT;
  put / '      (RT x QuadTime)MS = ' RTQuadTMS;
  put /'      F(RT x QuadT) = ' FRTQuadT 'p-value = ' pRTQuadT;
  output;
end;
run;

/* SPLIT-SPLIT-PLOT part (Will do this in pieces, to try to avoid mistakes in
using the outstat datasets-pull together results at end */
proc glm data=one outstat=junk3;
title1 "Split-Split pieces: CT, and CT contrasts";
class CT;
model mc=CT/ss3;
contrast "Linear CT" CT -1 0 1;
contrast "Quad CT" CT -1 2 -1;
run;
proc print data=junk3;
title2 "Do we have <junk3>"; run; /*Yes*/

data splitsplit;
set ER junk3; /*merge Error a/b/c dataset with junk3 */
keep _SOURCE_ DF SS;
proc print;
title2 "Do we have <splitsplit>"; run; /*Yes*/
run; title2 ' ';
data splitsplit; set splitsplit end=last;
title1 "Split-Split pieces: CT, and CT contrasts";
retain div dfE dfCT CT LinCT QuadCT 0;
if _N_ = 3 then dfE=DF; else dfE=dfE+0;     /*This is Error(c) */
if _N_ = 3 then div=SS/DF; else div=div+0;
if _N_ = 5 then dfCT=DF; else dfCT=dfCT+0;   /*CT df */
if _N_ = 5 then CT = SS; else CT=CT+0;  /* CT SS */
if _N_ = 6 then LinCT=SS; else LinCT=LinCT+0;
if _N_ = 7 then QuadCT=SS; else QuadCT=QuadCT+0;
if last then do;
  /*to find F and p-values for CT, Lin/Quad CT */
  CTMS=CT/dfCT;
  FCT=CTMS/div; pCT=1-probf(FCT,dfCT,dfE);
  LinCTMS=LinCT; QuadCTMS=QuadCT; /* df=1 here */
  FLinCT=LinCTMS/div; pLinCT=1-probf(FLinCT,1,dfE);
  FQuadCT=QuadCTMS/div; pQuadCT=1-probf(FQuadCT,1,dfE);
  file print;
  put ///'     (CT)SS = ' CT;
  put / '      (CT)MS = ' CTMS;
  put /'      F(CT) = ' FCT 'p-value = ' pCT;
  put ///'     (Linear CT)SS = ' LinCT;
  put / '      (Linear CT)MS = ' LinCTMS;
  put /'      F(LinCT) = ' FLinCT 'p-value = ' pLinCT;
  put ///'     (Quad CT)SS = ' QuadCT;
  put / '      (Quad CT)MS = ' QuadCTMS;
  put /'      F(Quad CT) = ' FQuadCT 'p-value = ' pQuadCT;
  output;
```

```
end;
run;

/* CT x Time contrasts */
proc glm data=one outstat=junk32;
title1 "Split-Split pieces: CT x Time contrasts";
class CT time;
model mc=CT|time /ss3;
contrast "LinCTxLinTime" CT*time 1 0 -1 0 0 0 -1 0 1;
contrast "LinCTxQuadTime" CT*time 1 -2 1 0 0 0 -1 2 -1;
contrast "QuadCTxLinTime" CT*time 1 0 -1 -2 0 2 1 0 -1;
contrast "QuadCTxQuadTime" CT*time 1 -2 1 -2 4 -2 1 -2 1;
run;
proc print data=junk32;
title2 "Do we have <junk32>"; run; /*Yes*/

data splitsplit2;
set ER junk32; /*merge Error a/b/c dataset with junk32 */
keep _SOURCE_ DF SS;
proc print;
title2 "Do we have <splitsplit2>"; run; /*Yes*/
run; title2 ' ';
data splitsplit2; set splitsplit2 end=last;
title "Split-Split pieces: CT, CT x Time contrasts";
retain div dfE dfCTtime CTtime C1 C2 C3 C4 0;
             /*C1==LinCTLinT,C2=LinCTQuadT,C3=QuadCTLinT,C4=QuadCTQuadT*/
if _N_ = 3 then dfE=DF; else dfE=dfE+0;     /*This is Error(c) */
if _N_ = 3 then div=SS/DF; else div=div+0;
if _N_ = 7 then dfCTtime=DF; else dfCTtime=dfCTtime+0; /* df CTxTime */
if _N_ = 7 then CTtime=SS; else CTtime=CTtime+0;   /* CTxTime SS */
if _N_ = 8 then C1=SS; else C1=C1+0;
if _N_ = 9 then C2=SS; else C2=C2+0;
if _N_ = 10 then C3=SS; else C3=C3+0;
if _N_ = 11 then C4=SS; else C4=C4+0;
if last then do;
  /*to find F and p-values CT x Time and components */
  CTtimeMS=CTtime/dfCTtime;
  FCTtime=CTtimeMS/div; pCTtime=1-probf(FCTtime,dfCTtime,dfE);
  C1MS=C1; C2MS=C2;C3MS=C3;C4MS=C4; /* df=1 here */
  FC1=C1MS/div; pC1=1-probf(FC1,1,dfE);
  FC2=C2MS/div; pC2=1-probf(FC2,1,dfE);
  FC3=C3MS/div; pC3=1-probf(FC3,1,dfE);
  FC4=C4MS/div; pC4=1-probf(FC4,1,dfE);
  file print;
  put ///'     (CT x Time)SS = ' CTtime;
  put / '      (CT x Time)MS = ' CTtimeMS;
  put /'      F(CT x Time) = ' FCTtime 'p-value = ' pCTtime;
  put ///'     (LinearCT x LinearTime)SS = ' C1;
  put / '      (LinearCT x LinearTime)MS = ' C1MS;
  put /'      F(LinCT x LinTime) = ' FC1 'p-value = ' pC1;
  put ///'     (LinearCT x Quadratic Time)SS = ' C2;
  put / '      (LinearCT x Quadratic Time)MS = ' C2MS;
  put /'      F(LinCT x QuadTime) = ' FC2 'p-value = ' pC2;
  put ///'     (QuadraticCT x LinearTime)SS = ' C3;
  put / '      (QuadraticCT x LinearTime)MS = ' C3MS;
  put /'      F(QuadCT x LinTime) = ' FC3 'p-value = ' pC3;
  put ///'     (QuadraticCT x QuadraticTime)SS = ' C4;
```

```
  put / '       (QuadraticCT x QuadraticTime)MS = ' C4MS;
  put /'      F(QuadCT x QuadTime) = ' FC4 'p-value = ' pC4;
  output;
end;
run;

/*CT x RT pieces */
proc glm data=one outstat=junk33;
title1 "Split-Split pieces: RTxCT and Linear components";
class RT CT;
model mc=RT|CT/ss3;
contrast "Linear CT" CT -1 0 1;
contrast "LinearCT@RT1" CT -1 0 1 RT*CT -1 0 1;
contrast "LinearCT@RT2" CT -1 0 1 RT*CT 0 0 0 -1 0 1;
run;

proc print data=junk33;
title2 "Do we have <junk33>"; run; /*Yes*/

/*Find RT x LinearCT Contrast*/
data splitsplit3;
set ER junk33;  /*merge Error a/b/c dataset with junk33 */
keep _SOURCE_ DF SS;
proc print;
title2 "Do we have <splitsplit3>"; run; /*Yes*/
run; title2 ' ';

data splitsplit3; set splitsplit3 end=last;
title1 "Split-Split pieces: RT x CT and Linear contrasts";
retain div dfE dfRT dfRTCT RTCT RTLinCT 0;
if _N_ = 3 then dfE=DF; else dfE=dfE+0;     /*This is Error(c) */
if _N_ = 3 then div=SS/DF; else div=div+0;
if _N_ = 5 then dfRT=DF; else dfRT=dfRT+0;  /*df for RTxLinCT*/
if _N_ = 7 then dfRTCT=DF; else dfRTCT=dfRTCT+0; /*df for RTxCT */
if _N_ = 7 then RTCT=SS; else RTCT=RTCT+0; /*RTxCT SS */
if _N_ < 8 then SS=0;
else if _N_ = 8 then SS=-SS;
RTLinCT=RTLinCT+SS;  /* RTxLinCT SS */
if last then do;
  /*to find F and p-values for RTxCT, RTxLinCT */
  RTCTMS=RTCT/dfRTCT;
  FRTCT=RTCTMS/div; pRTCT=1-probf(FRTCT,dfRTCT,dfE);
  RTLinCTMS=RTLinCT/dfRT;
  FRTLinCT=RTLinCTMS/div; pRTLinCT=1-probf(FRTLinCT,dfRT,dfE);
  file print;
  put ///'     (RTxCT)SS = ' RTCT;
  put / '      (RTxCT)MS = ' RTCTMS;
  put /'      F(RTxCT) = ' FRTCT 'p-value = ' pRTCT;
  put ///'     (RT x LinearCT)SS = ' RTLinCT;
  put / '      (RT x LinearCT)MS = ' RTLinCTMS;
  put /'      F(RT x LinCT) = ' FRTLinCT 'p-value = ' pRTLinCT;
  output;
end;
run;

proc glm data=one outstat=junk34;
title1 "Split-Split pieces: RTxCT Quadratic components";
```

```
class RT CT;
model mc=RT|CT/ss3;
contrast "Quadratic CT" CT -1 2 -1;
contrast "QuadraticCT@RT1" CT -1 2 -1 RT*CT -1 2 -1;
contrast "Quadratic@RT2" CT -1 2 -1 RT*CT 0 0 0 -1 2 -1;
run;

proc print data=junk34;
title2 "Do we have <junk34>"; run; /*Yes*/

/*Find RT x QuadCT Contrast*/
data splitsplit4;
set ER junk34;  /*merge Error a/b/c dataset with junk34 */
keep _SOURCE_ DF SS;
proc print;
title2 "Do we have <splitsplit4>"; run; /*Yes*/
run; title2 ' ';

data splitsplit4; set splitsplit4 end=last;
title1 "Split-Split pieces: RT x CT Quadratic contrasts";
retain div dfE dfRT RTQuadCT 0;
if _N_ = 3 then dfE=DF; else dfE=dfE+0;     /*This is Error(c) */
if _N_ = 3 then div=SS/DF; else div=div+0;
if _N_ = 5 then dfRT=DF; else dfRT=dfRT+0;  /*df for RTxQuadCT*/
if _N_ < 8 then SS=0;
else if _N_ = 8 then SS=-SS;
RTQuadCT=RTQuadCT+SS;  /* RTxQuadCT SS */
if last then do;
  /*to find F and p-values for RTxQuadCT */
  RTQuadCTMS=RTQuadCT/dfRT;
  FRTQuadCT=RTQuadCTMS/div; pRTQuadCT=1-probf(FRTQuadCT,dfRT,dfE);
  file print;
  put ///'     (RT x QuadraticCT)SS = ' RTQuadCT;
  put / '      (RT x QuadraticCT)MS = ' RTQuadCTMS;
  put /'      F(RT x QuadraticCT) = ' FRTQuadCT 'p-value = ' pRTQuadCT;
  output;
end;
run;

/*size RT time pieces */
proc glm data=one outstat=junk35;
title1 "Split-Split pieces: size, RT, time and Linear components";
class size RT time;
model mc=size|RT|time/ss3;
contrast "Linear Time" time -1 0 1;
contrast "LinT@size1" time -1 0 1 size*time -1 0 1;
contrast "LinT@size2" time -1 0 1 size*time 0 0 0 -1 0 1;
run;

proc print data=junk35;
title2 "Do we have <junk35>"; run; /*Yes*/

/*Find Size, sizextime, sizexRTxtime*/
data splitsplit5;
set ER junk35;  /*merge Error a/b/c dataset with junk35 */
keep _SOURCE_ DF SS;
proc print;
```

```
title2 "Do we have <splitsplit5>"; run; /*Yes*/
run; title2 ' ';

data splitsplit5; set splitsplit5 end=last;
title1 "Split-Split pieces: size, RT, time and Linear contrasts";
retain div dfE dfS dfSRT dfStime dfSRTtime Size SRT Stime SRTtime SLinT 0;
if _N_ = 3 then dfE=DF; else dfE=dfE+0;     /*This is Error(c) */
if _N_ = 3 then div=SS/DF; else div=div+0;
if _N_ = 5 then dfS=DF; else dfS=dfS+0;  /*df for SizexLinT, size*/
if _N_ = 5 then Size=SS; else Size=Size+0; /* Size SS */
if _N_ = 7 then dfSRT=DF; else dfSRT=dfSRT+0; /*df for sizexRT */
if _N_ = 7 then SRT=SS; else SRT=SRT+0; /*sizexRT SS */
if _N_ = 9 then dfStime=DF; else dfStime=dfStime+0;  /* size x time df */
if _N_ = 9 then Stime=SS; else Stime=Stime+0; /* sizexTime SS */
if _N_ = 11 then dfSRTtime=DF; else dfSRTtime=dfSRTtime+0;  /* df for
sizexRTxtime */
if _N_ = 11 then SRTtime=SS; else SRTtime=SRTtime+0;  /* size x RT x time SS
*/
if _N_ < 12 then SS=0;
else if _N_ = 12 then SS=-SS;
SLinT=SLinT+SS;  /* sizexLinTime SS */
if last then do;
  /*to find F and p-values  */
  SizeMS=Size/dfS;
  FSize=SizeMS/div; pSize=1-probf(FSize,dfS,dfE);
  SRTMS= SRT/dfSRT;
  FSRT=SRTMS/div; pSRT=1-probf(FSRT,dfSRT,dfE);
  StimeMS=Stime/dfStime;
  FStime=StimeMS/div; pStime=1-probf(FStime,dfStime,dfE);
  SRTtimeMS=SRTtime/dfSRTtime;
  FSRTtime=SRTtimeMS/div; pSRTtime=1-probf(FSRTtime,dfSRTtime,dfE);
  SLinTMS=SLinT/dfS;
  FSLinT=SLinTMS/div; pSLinT=1-probf(FSLinT,dfS,dfE);
  file print;
  put ///'     (Size)SS  = ' Size;
  put / '      (Size)MS = ' SizeMS;
  put /'      F(Size) = ' FSize 'p-value = ' pSize;
  put///'      (SizexRT)SS  =  ' SRT;
  put/ '       (SizexRT)MS  =  ' SRTMS;
  put/ '      F(SizexRT)  =  ' FSRT ' p-value = ' pSRT;
  put///'      (SizexTime)SS = ' Stime;
  put/ '       (SizexTime)MS = ' StimeMS;
  put/ '      F(SizexTime)  =  ' FStime '  p-value = ' pStime;
  put///'       (SizexRTxTime)SS = ' SRTtime;
  put/'        (SizexRTxTime)MS = ' SRTtimeMS;
  put/ '      F(SizexRTxTime) = ' FSRTtime  '   p-value = ' pSRTtime;
  put ///'     (Size x LinearT)SS = ' SLinT;
  put / '      (Size x LinearT)MS = ' SLinTMS;
  put /'      F(Size x LinearT) = ' FSLinT 'p-value = ' pSLinT;
  output;
end;
run;

proc glm data=one outstat=junk36;
title1 "Split-Split pieces: size time quadratic components";
class size time;
model mc=size|time/ss3;
```

```
contrast "Quadratic Time" time -1 2 -1;
contrast "QuadT@size1" time -1 2 -1 size*time -1 2 -1;
contrast "QuadT@size2" time -1 2 -1 size*time 0 0 0 -1 2 -1;
run;

proc print data=junk36;
title2 "Do we have <junk36>"; run; /*Yes*/

/*Find size x QuadraticTime Contrast*/
data splitsplit6;
set ER junk36;  /*merge Error a/b/c dataset with junk36 */
keep _SOURCE_ DF SS;
proc print;
title2 "Do we have <splitsplit6>"; run; /*Yes*/
run; title2 ' ';
data splitsplit6; set splitsplit6 end=last;
title1 "Split-Split pieces: Size Time Quadratic contrasts";
retain div dfE dfS SQuadT 0;
if _N_ = 3 then dfE=DF; else dfE=dfE+0;     /*This is Error(c) */
if _N_ = 3 then div=SS/DF; else div=div+0;
if _N_ = 5 then dfS=DF; else dfS=dfS+0;  /*df for SizexQuadT*/
if _N_ < 8 then SS=0;
else if _N_ = 8 then SS=-SS;
SQuadT=SQuadT+SS;  /* SizexQuadT SS */
if last then do;
  /*to find F and p-values for SizexQuadT */
  SQuadTMS=SQuadT/dfS;
  FSQuadT=SQuadTMS/div; pSQuadT=1-probf(FSQuadT,dfS,dfE);
  file print;
  put ///'     (Size x QuadTime)SS = ' SQuadT;
  put / '      (Size x QuadTime)MS = ' SQuadTMS;
  put /'      F(Size x QuadTime) = ' FSQuadT 'p-value = ' pSQuadT;
  output;
end;
run;

/*size CT pieces */
proc glm data=one outstat=junk37;
title1 "Split-Split pieces: size CT Linear components";
class size CT;
model mc=size|CT/ss3;
contrast "Linear CT" CT -1 0 1;
contrast "LinCT@size1" CT -1 0 1 size*CT -1 0 1;
contrast "LinCT@size2" CT -1 0 1 size*CT 0 0 0 -1 0 1;
run;

proc print data=junk37;
title2 "Do we have <junk37>"; run; /*Yes*/

/*Find SizexCT, size x LinearCT Contrast*/
data splitsplit7;
set ER junk37;  /*merge Error a/b/c dataset with junk37 */
keep _SOURCE_ DF SS;
proc print;
title2 "Do we have <splitsplit7>"; run; /*Yes*/
run; title2 ' ';
```

```
data splitsplit7; set splitsplit7 end=last;
title1 "Split-Split pieces: size, CT Linear contrasts";
retain div dfE dfS dfSCT SCT SLinCT 0;
if _N_ = 3 then dfE=DF; else dfE=dfE+0;     /*This is Error(c) */
if _N_ = 3 then div=SS/DF; else div=div+0;
if _N_ = 5 then dfS=DF; else dfS=dfS+0;  /*df for SizexLinCT */
if _N_ = 7 then dfSCT=DF; else dfSCT=dfSCT+0; /*df for sizexCT */
if _N_ = 7 then SCT=SS; else SCT=SCT+0; /*sizexCT SS */
if _N_ < 8 then SS=0;
else if _N_ = 8 then SS=-SS;
SLinCT=SLinCT+SS;  /* sizexLinTime SS */
if last then do;
  /*to find F and p-values  */
  SCTMS= SCT/dfSCT;
  FSCT=SCTMS/div; pSCT=1-probf(FSCT,dfSCT,dfE);
  SLinCTMS=SLinCT/dfS;
  FSLinCT=SLinCTMS/div; pSLinCT=1-probf(FSLinCT,dfS,dfE);
  file print;
  put///'      (SizexCT)SS  =  ' SCT;
  put/ '       (SizexCT)MS  =  ' SCTMS;
  put/ '      F(SizexCT)  =  ' FSCT ' p-value = ' pSCT;
  put ///'     (Size x LinearCT)SS = ' SLinCT;
  put / '      (Size x LinearCT)MS = ' SLinCTMS;
  put /'      F(Size x LinearCT) = ' FSLinCT 'p-value = ' pSLinCT;
  output;
end;
run;

proc glm data=one outstat=junk38;
title1 "Split-Split pieces: size CT quadratic components";
class size CT;
model mc=size|CT/ss3;
contrast "Quadratic CT" CT -1 2 -1;
contrast "QuadCT@size1" CT -1 2 -1 size*CT -1 2 -1;
contrast "QuadCT@size2" CT -1 2 -1 size*CT 0 0 0 -1 2 -1;
run;

proc print data=junk38;
title2 "Do we have <junk38>"; run; /*Yes*/

/*Find size x Quadratic CT Contrast*/
data splitsplit8;
set ER junk38;  /*merge Error a/b/c dataset with junk38 */
keep _SOURCE_ DF SS;
proc print;
title2 "Do we have <splitsplit8>"; run; /*Yes*/
run; title2 ' ';
data splitsplit8; set splitsplit8 end=last;
title1 "Split-Split pieces: Size CT Quadratic contrasts";
retain div dfE dfS SQuadCT 0;
if _N_ = 3 then dfE=DF; else dfE=dfE+0;     /*This is Error(c) */
if _N_ = 3 then div=SS/DF; else div=div+0;
if _N_ = 5 then dfS=DF; else dfS=dfS+0;  /*df for SizexQuadCT*/
if _N_ < 8 then SS=0;
else if _N_ = 8 then SS=-SS;
SQuadCT=SQuadCT+SS;  /* SizexQuadCT SS */
if last then do;
```

```
  /*to find F and p-values for SizexQuadCT */
  SQuadCTMS=SQuadCT/dfS;
  FSQuadCT=SQuadCTMS/div; pSQuadCT=1-probf(FSQuadCT,dfS,dfE);
  file print;
  put ///'      (Size x Quad CT)SS = ' SQuadCT;
  put / '       (Size x Quad CT)MS = ' SQuadCTMS;
  put /'       F(Size x Quad CT) = ' FSQuadCT 'p-value = ' pSQuadCT;
  output;
end;
run;



/*abrade CT pieces */
proc glm data=one outstat=junk39;
title1 "Split-Split pieces: abrade CT Linear components";
class abrade CT;
model mc=abrade|CT/ss3;
contrast "Linear CT" CT -1 0 1;
contrast "LinCT@abrade1" CT -1 0 1 abrade*CT -1 0 1;
contrast "LinCT@abrade2" CT -1 0 1 abrade*CT 0 0 0 -1 0 1;
run;

proc print data=junk39;
title2 "Do we have <junk39>"; run; /*Yes*/

/*Find abrade, abradexCT, abrade x LinearCT Contrast*/
data splitsplit9;
set ER junk39;  /*merge Error a/b/c dataset with junk39 */
keep _SOURCE_ DF SS;
proc print;
title2 "Do we have <splitsplit9>"; run; /*Yes*/
run; title2 ' ';

data splitsplit9; set splitsplit9 end=last;
title1 "Split-Split pieces: Abrade, CT Linear contrasts";
retain div dfE dfAb dfAbCT Ab AbCT AbLinCT 0;
if _N_ = 3 then dfE=DF; else dfE=dfE+0;     /*This is Error(c) */
if _N_ = 3 then div=SS/DF; else div=div+0;
if _N_ = 5 then dfAb=DF; else dfAb=dfAb+0;  /*df for AbradexLinCT, and Abrade
*/
if _N_ = 5 then Ab=SS; else Ab=Ab+0;  /*Abrade SS*/
if _N_ = 7 then dfAbCT=DF; else dfAbCT=dfAbCT+0; /*df for AbradexCT */
if _N_ = 7 then AbCT=SS; else AbCT=AbCT+0; /*AbradexCT SS */
if _N_ < 8 then SS=0;
else if _N_ = 8 then SS=-SS;
AbLinCT=AbLinCT+SS;  /* abradexLinCT SS */
if last then do;
  /*to find F and p-values  */
  AbMS=Ab/dfAb;
  FAb=AbMS/div; pAb=1-probf(FAb,dfAb,dfE);
  AbCTMS= AbCT/dfAbCT;
  FAbCT=AbCTMS/div; pAbCT=1-probf(FAbCT,dfAbCT,dfE);
  AbLinCTMS=AbLinCT/dfAb;
  FAbLinCT=AbLinCTMS/div; pAbLinCT=1-probf(FAbLinCT,dfAb,dfE);
  file print;
  put///'      (Abrade)SS = ' Ab;
```

```
  put/ '        (Abrade)MS = ' AbMS;
  put/ '       F(Abrade) = ' FAb '   p-value = ' pAb;
  put///'       (AbradexCT)SS  =  ' AbCT;
  put/ '        (AbradexCT)MS  =  ' AbCTMS;
  put/ '       F(AbradexCT)  =  ' FAbCT ' p-value = ' pAbCT;
  put ///'      (Abrade x LinearCT)SS = ' AbLinCT;
  put / '       (Abrade x LinearCT)MS = ' AbLinCTMS;
  put /'       F(Abrade x LinearCT) = ' FAbLinCT 'p-value = ' pAbLinCT;
  output;
end;
run;

proc glm data=one outstat=junk310;
title1 "Split-Split pieces: Abrade CT quadratic components";
class abrade CT;
model mc=abrade|CT/ss3;
contrast "Quadratic CT" CT -1 2 -1;
contrast "QuadCT@abrade1" CT -1 2 -1 abrade*CT -1 2 -1;
contrast "QuadCT@abrade2" CT -1 2 -1 abrade*CT 0 0 0 -1 2 -1;
run;

proc print data=junk310;
title2 "Do we have <junk310>"; run; /*Yes*/

/*Find abrade x Quadratic CT Contrast*/
data splitsplit10;
set ER junk310;  /*merge Error a/b/c dataset with junk310 */
keep _SOURCE_ DF SS;
proc print;
title2 "Do we have <splitsplit10>"; run; /*Yes*/
run; title2 ' ';
data splitsplit10; set splitsplit10 end=last;
title1 "Split-Split pieces: abrade CT Quadratic contrasts";
retain div dfE dfAb AbQuadCT 0;
if _N_ = 3 then dfE=DF; else dfE=dfE+0;     /*This is Error(c) */
if _N_ = 3 then div=SS/DF; else div=div+0;
if _N_ = 5 then dfAb=DF; else dfAb=dfAb+0;  /*df for abradexQuadCT*/
if _N_ < 8 then SS=0;
else if _N_ = 8 then SS=-SS;
AbQuadCT=AbQuadCT+SS;  /* abradexQuadCT SS */
if last then do;
  /*to find F and p-values for abradexQuadCT */
  AbQuadCTMS=AbQuadCT/dfAb;
  FAbQuadCT=AbQuadCTMS/div; pAbQuadCT=1-probf(FAbQuadCT,dfAb,dfE);
  file print;
  put ///'     (abrade x Quad CT)SS = ' AbQuadCT;
  put / '      (abrade x Quad CT)MS = ' AbQuadCTMS;
  put /'      F(abrade x Quad CT) = ' FAbQuadCT 'p-value = ' pAbQuadCT;
  output;
end;
run;


/*abrade time pieces */
proc glm data=one outstat=junk311;
title1 "Split-Split pieces: abrade time Linear components";
class abrade time;
```

```
model mc=abrade|time/ss3;
contrast "Linear Time" time -1 0 1;
contrast "LinT@abrade1" time -1 0 1 abrade*time -1 0 1;
contrast "LinT@abrade2" time -1 0 1 abrade*time 0 0 0 -1 0 1;
run;

proc print data=junk311;
title2 "Do we have <junk311>"; run; /*Yes*/

/*Find abradextime, abrade x LinearTime Contrast*/
data splitsplit11;
set ER junk311;  /*merge Error a/b/c dataset with junk311 */
keep _SOURCE_ DF SS;
proc print;
title2 "Do we have <splitsplit11>"; run; /*Yes*/
run; title2 ' ';

data splitsplit11; set splitsplit11 end=last;
title1 "Split-Split pieces: Abrade, time Linear contrasts";
retain div dfE dfAb dfAbT AbT AbLinT 0;
if _N_ = 3 then dfE=DF; else dfE=dfE+0;     /*This is Error(c) */
if _N_ = 3 then div=SS/DF; else div=div+0;
if _N_ = 5 then dfAb=DF; else dfAb=dfAb+0;  /*df for AbradexLinTime */
if _N_ = 7 then dfAbT=DF; else dfAbT=dfAbT+0; /*df for AbradexT */
if _N_ = 7 then AbT=SS; else AbT=AbT+0; /*AbradexT SS */
if _N_ < 8 then SS=0;
else if _N_ = 8 then SS=-SS;
AbLinT=AbLinT+SS;  /* abradexLinTime SS */
if last then do;
  /*to find F and p-values  */
  AbTMS= AbT/dfAbT;
  FAbT=AbTMS/div; pAbT=1-probf(FAbT,dfAbT,dfE);
  AbLinTMS=AbLinT/dfAb;
  FAbLinT=AbLinTMS/div; pAbLinT=1-probf(FAbLinT,dfAb,dfE);
  file print;
  put///'      (AbradexTime)SS  =  ' AbT;
  put/ '       (AbradexTime)MS  =  ' AbTMS;
  put/ '      F(AbradexTime)   =  ' FAbT ' p-value = ' pAbT;
  put ///'     (Abrade x LinearTime)SS = ' AbLinT;
  put / '      (Abrade x LinearTime)MS = ' AbLinTMS;
  put /'      F(Abrade x LinearTime) = ' FAbLinT 'p-value = ' pAbLinT;
  output;
end;
run;

proc glm data=one outstat=junk312;
title1 "Split-Split pieces: Abrade time quadratic components";
class abrade time;
model mc=abrade|time/ss3;
contrast "Quadratic Time" time -1 2 -1;
contrast "QuadT@abrade1" time -1 2 -1 abrade*time -1 2 -1;
contrast "QuadT@abrade2" time -1 2 -1 abrade*time 0 0 0 -1 2 -1;
run;

proc print data=junk312;
title2 "Do we have <junk312>"; run; /*Yes*/
```

```
/*Find abrade x Quadratic time Contrast*/
data splitsplit12;
set ER junk312;  /*merge Error a/b/c dataset with junk312 */
keep _SOURCE_ DF SS;
proc print;
title2 "Do we have <splitsplit12>"; run; /*Yes*/
run; title2 ' ';
data splitsplit12; set splitsplit12 end=last;
title1 "Split-Split pieces: abrade time Quadratic contrasts";
retain div dfE dfAb AbQuadT 0;
if _N_ = 3 then dfE=DF; else dfE=dfE+0;     /*This is Error(c) */
if _N_ = 3 then div=SS/DF; else div=div+0;
if _N_ = 5 then dfAb=DF; else dfAb=dfAb+0;  /*df for abradexQuadT*/
if _N_ < 8 then SS=0;
else if _N_ = 8 then SS=-SS;
AbQuadT=AbQuadT+SS;  /* abradexQuadT SS */
if last then do;
  /*to find F and p-values for abradexQuadT */
  AbQuadTMS=AbQuadT/dfAb;
  FAbQuadT=AbQuadTMS/div; pAbQuadT=1-probf(FAbQuadT,dfAb,dfE);
  file print;
  put ///'     (abrade x Quad Time)SS = ' AbQuadT;
  put / '      (abrade x Quad Time)MS = ' AbQuadTMS;
  put /'      F(abrade x Quad Time) = ' FAbQuadT 'p-value = ' pAbQuadT;
  output;
end;
run;


/*The rest of the story... pieces */
proc glm data=one outstat=junk313;
title1 "Split-Split pieces: not previously covered";
class CT RT time size abrade;
model mc=CT*RT*time size*RT size*CT*time size*RT*time size*CT*RT
size*CT*RT*time
   abrade*RT abrade*RT*time abrade*CT*time abrade*CT*RT  abrade*CT*RT*time
   abrade*size abrade*size*time abrade*size*RT abrade*size*RT*time
   abrade*size*CT abrade*size*CT*time abrade*size*CT*RT
   abrade*size*CT*RT*time/ss3;

run;

proc print data=junk313;
title2 "Do we have <junk313>"; run; /*Yes*/

/*Rest of values*/
data splitsplit13;
set junk313 ER;  /*merge Error a/b/c dataset with junk313 */
keep _SOURCE_ DF SS; output;
proc print;
title2 "Do we have <splitsplit13>"; run; /*Yes*/
run; title2 ' ';

proc iml;
use splitsplit13;
read all var {DF SS} into P;
nr=nrow(P);
```

```
FM=J(nr,5,0);
FM[1:nr,1:2]=P[1:nr,1:2];
do r = 1 to nr;
    FM[r,3]=FM[r,2]/FM[r,1];
end;
MSEc=FM[nr,3]; dfE=FM[nr,1];
/*print P FM MSEc; */
do r = 1 to nr;
    FM[r,4]=FM[r,3]/MSEc;
      FM[r,5]=1-probf(FM[r,4],FM[r,1],dfE);
end;
/*print MSEc dfE FM; */
varnames={DF SS MS F p};
create outFP from FM (|colname=varnames|);
append from FM;
run;

data yes;
merge splitsplit13 outFP;
proc print data=yes;
title2 "The rest of the F and p values"; run;
quit;
```

OUTPUT FOR MOISTURE CONTENT (FRESH)

Batch Vacuum-belt Drying Analysis 23 May 2010 1

The GLM Procedure

Class Level Information

Class	Levels	Values
rep	9	1 2 3 4 5 6 7 8 9
abrade	2	1 2
size	2	1 2
CT	3	1 2 3
RT	2	1 2
time	3	1 2 3

Number of Observations Read	648
Number of Observations Used	648

Dependent Variable: mc

Source	DF	Sum of Squares	Mean Square	F Value
Model	647	23.10011087	0.03570342	.
Error	0	0.00000000	.	
Corrected Total	647	23.10011087		

Source	Pr > F
Model	.

Error

Corrected Total

R-Square	Coeff Var	Root MSE	mc Mean
1.000000	.	.	0.184569

Source	DF	Type III SS	Mean Square	F Value
time	2	3.05794695	1.52897348	.
RT	1	0.99099735	0.99099735	.
RT*time	2	0.01136203	0.00568101	.
CT	2	9.56951959	4.78475980	.
CT*time	4	0.53354509	0.13338627	.
CT*RT	2	0.28306181	0.14153091	.
CT*RT*time	4	0.31712296	0.07928074	.
size	1	0.10772535	0.10772535	.
size*time	2	0.06970473	0.03485237	.

Source	Pr > F
time	.
RT	.
RT*time	.
CT	.
CT*time	.
CT*RT	.
CT*RT*time	.
size	.
size*time	.

Dependent Variable: mc

Source	DF	Type III SS	Mean Square	F Value
size*RT	1	0.00006485	0.00006485	.
size*RT*time	2	0.08407237	0.04203619	.
size*CT	2	0.02603793	0.01301896	.
size*CT*time	4	0.09967976	0.02491994	.
size*CT*RT	2	0.06752731	0.03376365	.
size*CT*RT*time	4	0.22663151	0.05665788	.
abrade	1	0.32890556	0.32890556	.
abrade*time	2	0.15707463	0.07853732	.
abrade*RT	1	0.05304748	0.05304748	.
abrade*RT*time	2	0.06521597	0.03260798	.
abrade*CT	2	0.03129046	0.01564523	.
abrade*CT*time	4	0.07950023	0.01987506	.
abrade*CT*RT	2	0.03005875	0.01502938	.
abrade*CT*RT*time	4	0.17074562	0.04268640	.
abrade*size	1	0.07392012	0.07392012	.
abrade*size*time	2	0.03921406	0.01960703	.
abrade*size*RT	1	0.01233322	0.01233322	.
abrade*size*RT*time	2	0.25004530	0.12502265	.
abrade*size*CT	2	0.05391244	0.02695622	.
abrade*size*CT*time	4	0.16714869	0.04178717	.
abrade*size*CT*RT	2	0.00648627	0.00324314	.
abra*size*CT*RT*time	4	0.15174647	0.03793662	.
rep	8	0.59303589	0.07412949	.
rep*time	16	0.17539207	0.01096200	.
rep*RT	8	0.04765189	0.00595649	.
rep*RT*time	16	0.11015228	0.00688452	.
rep*CT	16	0.21251552	0.01328222	.
rep*CT*time	32	0.14770788	0.00461587	.
rep*CT*RT	16	0.07655007	0.00478438	.
rep*CT*RT*time	32	0.32043823	0.01001369	.
rep*size	8	0.01751239	0.00218905	.

rep*size*time	16	0.06471191	0.00404449	.
rep*size*RT	8	0.03432888	0.00429111	.
rep*size*RT*time	16	0.18436043	0.01152253	.
rep*size*CT	16	0.23717780	0.01482361	.
rep*size*CT*time	32	0.31541727	0.00985679	.
rep*size*CT*RT	16	0.08398408	0.00524901	.
rep*size*CT*RT*time	32	0.26423419	0.00825732	.
rep*abrade	8	0.09216240	0.01152030	.
rep*abrade*time	16	0.20794545	0.01299659	.
rep*abrade*RT	8	0.08593336	0.01074167	.
rep*abrade*RT*time	16	0.05839506	0.00364969	.
rep*abrade*CT	16	0.27501538	0.01718846	.
rep*abrade*CT*time	32	0.57157102	0.01786159	.
rep*abrade*CT*RT	16	0.09294086	0.00580880	.
rep*abrad*CT*RT*time	32	0.32364152	0.01011380	.

Source	Pr > F
size*RT	.
size*RT*time	.
size*CT	.
size*CT*time	.
size*CT*RT	.
size*CT*RT*time	.
abrade	.
abrade*time	.
abrade*RT	.
abrade*RT*time	.
abrade*CT	.
abrade*CT*time	.
abrade*CT*RT	.
abrade*CT*RT*time	.
abrade*size	.
abrade*size*time	.
abrade*size*RT	.
abrade*size*RT*time	.
abrade*size*CT	.
abrade*size*CT*time	.
abrade*size*CT*RT	.
abra*size*CT*RT*time	.
rep	.
rep*time	.
rep*RT	.
rep*RT*time	.
rep*CT	.
rep*CT*time	.
rep*CT*RT	.
rep*CT*RT*time	.
rep*size	.
rep*size*time	.
rep*size*RT	.
rep*size*RT*time	.
rep*size*CT	.
rep*size*CT*time	.
rep*size*CT*RT	.
rep*size*CT*RT*time	.
rep*abrade	.
rep*abrade*time	.
rep*abrade*RT	.
rep*abrade*RT*time	.
rep*abrade*CT	.
rep*abrade*CT*time	.
rep*abrade*CT*RT	.
rep*abrad*CT*RT*time	.

Source	DF	Type III SS	Mean Square	F Value
rep*abrade*size	8	0.02491178	0.00311397	.

rep*abrade*size*time	16	0.18943807	0.01183988
rep*abrade*size*RT	8	0.03117812	0.00389727
rep*abr*size*RT*time	16	0.10940490	0.00683781
rep*abrade*size*CT	16	0.12517678	0.00782355
rep*abr*size*CT*time	32	0.22983318	0.00718229
rep*abrad*size*CT*RT	16	0.12027517	0.00751720
re*abr*siz*CT*RT*tim	32	0.56147217	0.01754601

Source	Pr > F
rep*abrade*size	.
rep*abrade*size*time	.
rep*abrade*size*RT	.
rep*abr*size*RT*time	.
rep*abrade*size*CT	.
rep*abr*size*CT*time	.
rep*abrad*size*CT*RT	.
re*abr*siz*CT*RT*tim	.

RT qual, Time quantitative; SOURCE, DF & SS data only....contrasts 7

Obs	_SOURCE_	DF	SS
1	ERROR	0	0.00000
2	time	2	3.05795
3	RT	1	0.99100
4	RT*time	2	0.01136
5	CT	2	9.56952
6	CT*time	4	0.53355
7	CT*RT	2	0.28306
8	CT*RT*time	4	0.31712
9	size	1	0.10773
10	size*time	2	0.06970
11	size*RT	1	0.00006
12	size*RT*time	2	0.08407
13	size*CT	2	0.02604
14	size*CT*time	4	0.09968
15	size*CT*RT	2	0.06753
16	size*CT*RT*time	4	0.22663
17	abrade	1	0.32891
18	abrade*time	2	0.15707
19	abrade*RT	1	0.05305
20	abrade*RT*time	2	0.06522
21	abrade*CT	2	0.03129
22	abrade*CT*time	4	0.07950
23	abrade*CT*RT	2	0.03006
24	abrade*CT*RT*time	4	0.17075
25	abrade*size	1	0.07392
26	abrade*size*time	2	0.03921
27	abrade*size*RT	1	0.01233
28	abrade*size*RT*time	2	0.25005
29	abrade*size*CT	2	0.05391
30	abrade*size*CT*time	4	0.16715
31	abrade*size*CT*RT	2	0.00649
32	abra*size*CT*RT*time	4	0.15175
33	rep	8	0.59304
34	rep*time	16	0.17539
35	rep*RT	8	0.04765
36	rep*RT*time	16	0.11015
37	rep*CT	16	0.21252
38	rep*CT*time	32	0.14771
39	rep*CT*RT	16	0.07655
40	rep*CT*RT*time	32	0.32044
41	rep*size	8	0.01751
42	rep*size*time	16	0.06471
43	rep*size*RT	8	0.03433
44	rep*size*RT*time	16	0.18436
45	rep*size*CT	16	0.23718
46	rep*size*CT*time	32	0.31542
47	rep*size*CT*RT	16	0.08398

Obs	_SOURCE_	DF	SS
48	rep*size*CT*RT*time	32	0.26423
49	rep*abrade	8	0.09216
50	rep*abrade*time	16	0.20795

RT qual, Time quantitative; SOURCE, DF & SS data only....contrasts 8

Obs	_SOURCE_	DF	SS
51	rep*abrade*RT	8	0.08593
52	rep*abrade*RT*time	16	0.05840
53	rep*abrade*CT	16	0.27502
54	rep*abrade*CT*time	32	0.57157
55	rep*abrade*CT*RT	16	0.09294
56	rep*abrad*CT*RT*time	32	0.32364
57	rep*abrade*size	8	0.02491
58	rep*abrade*size*time	16	0.18944
59	rep*abrade*size*RT	8	0.03118
60	rep*abr*size*RT*time	16	0.10940
61	rep*abrade*size*CT	16	0.12518
62	rep*abr*size*CT*time	32	0.22983
63	rep*abrad*size*CT*RT	16	0.12028
64	re*abr*siz*CT*RT*tim	32	0.56147

RT qual, Time quantitative; SOURCE, DF & SS data only....contrasts 9
06:58 Wednesday, August 3, 2005

ER	EC
16 0.1753921	16 0.2125155
24 0.1578042	32 0.1477079
528 5.0582339	16 0.0765501
	32 0.3204382
	8 0.0175124
	16 0.0647119
	8 0.0343289
	16 0.1843604
	16 0.2371778
	32 0.3154173
	16 0.0839841
	32 0.2642342
	8 0.0921624
	16 0.2079455
	8 0.0859334
	16 0.0583951
	16 0.2750154
	32 0.571571
	16 0.0929409
	32 0.3236415
	8 0.0249118
	16 0.1894381
	8 0.0311781
	16 0.1094049
	16 0.1251768
	32 0.2298332
	16 0.1202752
	32 0.5614722

Is this two2 10
06:58 Wednesday, August 3, 2005

Obs	_SOURCE_	DF	SS
1	ERROR	0	0.00000

Obs	_SOURCE_	DF	SS
2	time	2	3.05795
3	RT	1	0.99100
4	RT*time	2	0.01136
5	CT	2	9.56952
6	CT*time	4	0.53355
7	CT*RT	2	0.28306
8	CT*RT*time	4	0.31712
9	size	1	0.10773
10	size*time	2	0.06970
11	size*RT	1	0.00006
12	size*RT*time	2	0.08407
13	size*CT	2	0.02604
14	size*CT*time	4	0.09968
15	size*CT*RT	2	0.06753
16	size*CT*RT*time	4	0.22663
17	abrade	1	0.32891
18	abrade*time	2	0.15707
19	abrade*RT	1	0.05305
20	abrade*RT*time	2	0.06522
21	abrade*CT	2	0.03129
22	abrade*CT*time	4	0.07950
23	abrade*CT*RT	2	0.03006
24	abrade*CT*RT*time	4	0.17075
25	abrade*size	1	0.07392
26	abrade*size*time	2	0.03921
27	abrade*size*RT	1	0.01233
28	abrade*size*RT*time	2	0.25005
29	abrade*size*CT	2	0.05391
30	abrade*size*CT*time	4	0.16715
31	abrade*size*CT*RT	2	0.00649
32	abra*size*CT*RT*time	4	0.15175
33	rep	8	0.59304
34	rep*time	16	0.17539
35	rep*RT	8	0.04765
36	rep*RT*time	16	0.11015
37	rep*CT	16	0.21252
38	rep*CT*time	32	0.14771
39	rep*CT*RT	16	0.07655
40	rep*CT*RT*time	32	0.32044
41	rep*size	8	0.01751
42	rep*size*time	16	0.06471
43	rep*size*RT	8	0.03433
44	rep*size*RT*time	16	0.18436
45	rep*size*CT	16	0.23718
46	rep*size*CT*time	32	0.31542
47	rep*size*CT*RT	16	0.08398
48	rep*size*CT*RT*time	32	0.26423
49	rep*abrade	8	0.09216
50	rep*abrade*time	16	0.20795

Obs	_SOURCE_	DF	SS
51	rep*abrade*RT	8	0.08593
52	rep*abrade*RT*time	16	0.05840
53	rep*abrade*CT	16	0.27502
54	rep*abrade*CT*time	32	0.57157
55	rep*abrade*CT*RT	16	0.09294
56	rep*abrad*CT*RT*time	32	0.32364
57	rep*abrade*size	8	0.02491
58	rep*abrade*size*time	16	0.18944
59	rep*abrade*size*RT	8	0.03118
60	rep*abr*size*RT*time	16	0.10940
61	rep*abrade*size*CT	16	0.12518
62	rep*abr*size*CT*time	32	0.22983
63	rep*abrad*size*CT*RT	16	0.12028

64	re*abr*siz*CT*RT*tim	32	0.56147
65	ERRORA	16	0.17539
66	ERRORB	24	0.15780
67	ERRORC	528	5.05823

Whole Plot pieces: Time and reps 12
06:58 Wednesday, August 3, 2005

The GLM Procedure

Class Level Information

Class	Levels	Values
time	3	1 2 3
rep	9	1 2 3 4 5 6 7 8 9

Number of Observations Read 648
Number of Observations Used 648

Whole Plot pieces: Time and reps 13
06:58 Wednesday, August 3, 2005

The GLM Procedure

Dependent Variable: mc

Source	DF	Sum of Squares	Mean Square	F Value
Model	26	3.82637492	0.14716827	4.74
Error	621	19.27373596	0.03103661	
Corrected Total	647	23.10011087		

Source	Pr > F
Model	<.0001
Error	
Corrected Total	

R-Square	Coeff Var	Root MSE	mc Mean
0.165643	95.45031	0.176172	0.184569

Source	DF	Type III SS	Mean Square	F Value
time	2	3.05794695	1.52897348	49.26
rep	8	0.59303589	0.07412949	2.39
time*rep	16	0.17539207	0.01096200	0.35

Source	Pr > F
time	<.0001
rep	0.0153
time*rep	0.9911

Contrast	DF	Contrast SS	Mean Square	F Value

Linear Time	1	2.98319028	2.98319028	96.12
Quad Time	1	0.07475667	0.07475667	2.41

Contrast	Pr > F
Linear Time	<.0001
Quad Time	0.1212

Whole Plot pieces: Time and reps 14
06:58 Wednesday, August 3, 2005

The GLM Procedure

Dependent Variable: mc

Tests of Hypotheses Using the Type III
MS for time*rep as an Error Term

Source	DF	Type III SS	Mean Square	F Value
time	2	3.05794695	1.52897348	139.48
rep	8	0.59303589	0.07412949	6.76

Tests of Hypotheses Using
the Type III MS for time*rep
as an Error Term

Source	Pr > F
time	<.0001
rep	0.0006

Whole Plot pieces: Time and reps 15
Do we have <junk1>
06:58 Wednesday, August 3, 2005

Obs	_NAME_	_SOURCE_	_TYPE_	DF	SS	F	PROB
1	mc	ERROR	ERROR	621	19.2737	.	.
2	mc	time	SS3	2	3.0579	49.2635	0.00000
3	mc	rep	SS3	8	0.5930	2.3885	0.01535
4	mc	time*rep	SS3	16	0.1754	0.3532	0.99112
5	mc	Linear Time	CONTRAST	1	2.9832	96.1184	0.00000
6	mc	Quad Time	CONTRAST	1	0.0748	2.4087	0.12118

Whole Plot pieces: Time and reps 16
Time contrasts
06:58 Wednesday, August 3, 2005

(LinearTime)SS = 2.9831902801

(LinearTime)MS = 2.9831902801

F(LinT) = 272.13911879 p-value = 1.820699E-11

(QuadTime)SS = 0.0747566736

(QuadTime)MS = 0.0747566736

F(QuadT) = 6.8196170442 p-value = 0.0188963731

Split plot pieces: RT, RTxTime 17
06:58 Wednesday, August 3, 2005

The GLM Procedure

Class Level Information

Class	Levels	Values
RT	2	1 2
time	3	1 2 3

Number of Observations Read 648
Number of Observations Used 648

Split plot pieces: RT, RTxTime 18
06:58 Wednesday, August 3, 2005

The GLM Procedure

Dependent Variable: mc

Source	DF	Sum of Squares	Mean Square	F Value
Model	5	4.06030633	0.81206127	27.38
Error	642	19.03980455	0.02965702	
Corrected Total	647	23.10011087		

Source	Pr > F
Model	<.0001
Error	
Corrected Total	

R-Square	Coeff Var	Root MSE	mc Mean
0.175770	93.30479	0.172212	0.184569

Source	DF	Type III SS	Mean Square	F Value
RT	1	0.99099735	0.99099735	33.42
time	2	3.05794695	1.52897348	51.56
RT*time	2	0.01136203	0.00568101	0.19

Source	Pr > F
RT	<.0001
time	<.0001
RT*time	0.8257

Contrast	DF	Contrast SS	Mean Square	F Value
Linear Time	1	2.98319028	2.98319028	100.59
LinTime@RT1	1	1.64256896	1.64256896	55.39

LinTime@RT2 1 1.34789800 1.34789800 45.45

Contrast	Pr > F
Linear Time	<.0001
LinTime@RT1	<.0001
LinTime@RT2	<.0001

Split plot pieces: RT, RTxTime 19
Do we have <split1>
06:58 Wednesday, August 3, 2005

Obs	DF	SS	_SOURCE_
1	16	0.1754	ERRORA
2	24	0.1578	ERRORB
3	528	5.0582	ERRORC
4	642	19.0398	ERROR
5	1	0.9910	RT
6	2	3.0579	time
7	2	0.0114	RT*tim
8	1	2.9832	Linear
9	1	1.6426	LinTim
10	1	1.3479	LinTim

Split Plot pieces: RT, RT*Time and Linear contrasts 20
06:58 Wednesday, August 3, 2005

(RT)SS = 0.9909973472

(RT)MS = 0.9909973472

F(RT) = 150.71805033 p-value = 7.784995E-12

(RTxTime)SS = 0.0113620278

(RTxTime)MS = 0.0056810139

F(RTxTime) = 0.8640097167 p-value = 0.434168828

(RT x LinearTime)SS = 0.0072766875

(RT x LinearTime)MS = 0.0072766875

F(RT x LinT) = 1.1066913104 p-value = 0.3032796356

Split Plot pieces: RT by Quad Time contrasts 21
06:58 Wednesday, August 3, 2005

The GLM Procedure

Class Level Information

Class	Levels	Values
RT	2	1 2
time	3	1 2 3

Number of Observations Read 648
Number of Observations Used 648

Split Plot pieces: RT by Quad Time contrasts 22
06:58 Wednesday, August 3, 2005

The GLM Procedure

Dependent Variable: mc

Source	DF	Sum of Squares	Mean Square	F Value
Model	5	4.06030633	0.81206127	27.38
Error	642	19.03980455	0.02965702	
Corrected Total	647	23.10011087		

Source	Pr > F
Model	<.0001
Error	
Corrected Total	

R-Square	Coeff Var	Root MSE	mc Mean
0.175770	93.30479	0.172212	0.184569

Source	DF	Type III SS	Mean Square	F Value
RT	1	0.99099735	0.99099735	33.42
time	2	3.05794695	1.52897348	51.56
RT*time	2	0.01136203	0.00568101	0.19

Source	Pr > F
RT	<.0001
time	<.0001
RT*time	0.8257

Contrast	DF	Contrast SS	Mean Square	F Value
Quad Time	1	0.07475667	0.07475667	2.52
QuadTime@RT1	1	0.05689689	0.05689689	1.92
QuadTime@RT2	1	0.02194512	0.02194512	0.74

Contrast	Pr > F
Quad Time	0.1129
QuadTime@RT1	0.1665
QuadTime@RT2	0.3900

Split Plot pieces: RT by Quad Time contrasts 23
Do we have <split2>
06:58 Wednesday, August 3, 2005

Obs	DF	SS	_SOURCE_

1	16	0.1754	ERRORA
2	24	0.1578	ERRORB
3	528	5.0582	ERRORC
4	642	19.0398	ERROR
5	1	0.9910	RT
6	2	3.0579	time
7	2	0.0114	RT*tim
8	1	0.0748	Quad T
9	1	0.0569	QuadTi
10	1	0.0219	QuadTi

Split Plot pieces: RT by Quad Time contrast 24
06:58 Wednesday, August 3, 2005

(RT x QuadTime)SS = 0.0040853403

(RT x QuadTime)MS = 0.0040853403

F(RT x QuadT) = 0.6213281229 p-value = 0.4382710442

Split-Split pieces: CT, and CT contrasts 25
06:58 Wednesday, August 3, 2005

The GLM Procedure

Class Level Information

Class	Levels	Values
CT	3	1 2 3

Number of Observations Read 648
Number of Observations Used 648

Split-Split pieces: CT, and CT contrasts 26
06:58 Wednesday, August 3, 2005

The GLM Procedure

Dependent Variable: mc

Source	DF	Sum of Squares	Mean Square	F Value
Model	2	9.56951959	4.78475980	228.09
Error	645	13.53059128	0.02097766	
Corrected Total	647	23.10011087		

Source	Pr > F
Model	<.0001
Error	
Corrected Total	

R-Square	Coeff Var	Root MSE	mc Mean

0.414263 78.47272 0.144837 0.184569

Source	DF	Type III SS	Mean Square	F Value
CT	2	9.56951959	4.78475980	228.09

Source	Pr > F
CT	<.0001

Contrast	DF	Contrast SS	Mean Square	F Value
Linear CT	1	9.17408823	9.17408823	437.33
Quad CT	1	0.39543136	0.39543136	18.85

Contrast	Pr > F
Linear CT	<.0001
Quad CT	<.0001

Split-Split pieces: CT, and CT contrasts 27
Do we have <junk3>
06:58 Wednesday, August 3, 2005

Obs	_NAME_	_SOURCE_	_TYPE_	DF	SS	F	PROB
1	mc	ERROR	ERROR	645	13.5306	.	.
2	mc	CT	SS3	2	9.5695	228.088	1.2137E-75
3	mc	Linear CT	CONTRAST	1	9.1741	437.327	1.5676E-74
4	mc	Quad CT	CONTRAST	1	0.3954	18.850	.000016416

Split-Split pieces: CT, and CT contrasts 28
Do we have <splitsplit>
06:58 Wednesday, August 3, 2005

Obs	DF	SS	_SOURCE_
1	16	0.1754	ERRORA
2	24	0.1578	ERRORB
3	528	5.0582	ERRORC
4	645	13.5306	ERROR
5	2	9.5695	CT
6	1	9.1741	Linear
7	1	0.3954	Quad C

Split-Split pieces: CT, and CT contrasts 29
06:58 Wednesday, August 3, 2005

(CT)SS = 9.5695195926

(CT)MS = 4.7847597963

F(CT) = 499.45361112 p-value = 0

(Linear CT)SS = 9.1740882315

(Linear CT)MS = 9.1740882315

F(LinCT) = 957.63041219 p-value = 0

(Quad CT)SS = 0.3954313611

(Quad CT)MS = 0.3954313611

F(Quad CT) = 41.276810052 p-value = 2.953E-10

Split-Split pieces: CT x Time contrasts 30
06:58 Wednesday, August 3, 2005

The GLM Procedure

Class Level Information

Class	Levels	Values
CT	3	1 2 3
time	3	1 2 3

Number of Observations Read 648
Number of Observations Used 648

Split-Split pieces: CT x Time contrasts 31
06:58 Wednesday, August 3, 2005

The GLM Procedure

Dependent Variable: mc

Source	DF	Sum of Squares	Mean Square	F Value
Model	8	13.16101164	1.64512645	105.77
Error	639	9.93909924	0.01555415	
Corrected Total	647	23.10011087		

Source	Pr > F
Model	<.0001
Error	
Corrected Total	

R-Square	Coeff Var	Root MSE	mc Mean
0.569738	67.57146	0.124716	0.184569

Source	DF	Type III SS	Mean Square	F Value
CT	2	9.56951959	4.78475980	307.62
time	2	3.05794695	1.52897348	98.30
CT*time	4	0.53354509	0.13338627	8.58

Source	Pr > F
CT	<.0001

time	<.0001
CT*time	<.0001

Contrast	DF	Contrast SS	Mean Square	F Value
LinCTxLinTime	1	0.42812089	0.42812089	27.52
LinCTxQuadTime	1	0.05507223	0.05507223	3.54
QuadCTxLinTime	1	0.00520185	0.00520185	0.33

Contrast	Pr > F
LinCTxLinTime	<.0001
LinCTxQuadTime	0.0603
QuadCTxLinTime	0.5633

Split-Split pieces: CT x Time contrasts 32
06:58 Wednesday, August 3, 2005

The GLM Procedure

Dependent Variable: mc

Contrast	DF	Contrast SS	Mean Square	F Value
QuadCTxQuadTime	1	0.04515013	0.04515013	2.90

Contrast	Pr > F
QuadCTxQuadTime	0.0889

Split-Split pieces: CT x Time contrasts 33
Do we have <junk32>
06:58 Wednesday, August 3, 2005

Obs	_NAME_	_SOURCE_	_TYPE_	DF	SS	F	PROB
1	mc	ERROR	ERROR	639	9.93910	.	.
2	mc	CT	SS3	2	9.56952	307.620	0.00000
3	mc	time	SS3	2	3.05795	98.300	0.00000
4	mc	CT*time	SS3	4	0.53355	8.576	0.00000
5	mc	LinCTxLinTime	CONTRAST	1	0.42812	27.525	0.00000
6	mc	LinCTxQuadTime	CONTRAST	1	0.05507	3.541	0.06034
7	mc	QuadCTxLinTime	CONTRAST	1	0.00520	0.334	0.56326
8	mc	QuadCTxQuadTime	CONTRAST	1	0.04515	2.903	0.08891

Split-Split pieces: CT x Time contrasts 34
Do we have <splitsplit2>
06:58 Wednesday, August 3, 2005

Obs	DF	SS	_SOURCE_
1	16	0.17539	ERRORA
2	24	0.15780	ERRORB
3	528	5.05823	ERRORC
4	639	9.93910	ERROR
5	2	9.56952	CT
6	2	3.05795	time
7	4	0.53355	CT*tim
8	1	0.42812	LinCTx
9	1	0.05507	LinCTx
10	1	0.00520	QuadCT
11	1	0.04515	QuadCT

Split-Split pieces: CT, CT x Time contrasts 35
06:58 Wednesday, August 3, 2005

(CT x Time)SS = 0.5335450926

(CT x Time)MS = 0.1333862731

F(CT x Time) = 13.923427431 p-value = 8.329992E-11

(LinearCT x LinearTime)SS = 0.4281208889

(LinearCT x LinearTime)MS = 0.4281208889

F(LinCT x LinTime) = 44.689082222 p-value = 5.886347E-11

(LinearCT x Quadratic Time)SS = 0.0550722269

(LinearCT x Quadratic Time)MS = 0.0550722269

F(LinCT x QuadTime) = 5.7486736523 p-value = 0.0168474393

(QuadraticCT x LinearTime)SS = 0.0052018519

(QuadraticCT x LinearTime)MS = 0.0052018519

F(QuadCT x LinTime) = 0.5429914567 p-value = 0.4615228987

(QuadraticCT x QuadraticTime)SS = 0.045150125

(QuadraticCT x QuadraticTime)MS = 0.045150125

F(QuadCT x QuadTime) = 4.7129623918 p-value = 0.0303807922

Split-Split pieces: RTxCT and Linear components 36
06:58 Wednesday, August 3, 2005

The GLM Procedure

Class Level Information

Class	Levels	Values
RT	2	1 2
CT	3	1 2 3

Number of Observations Read 648
Number of Observations Used 648

Split-Split pieces: RTxCT and Linear components 37
06:58 Wednesday, August 3, 2005

The GLM Procedure

Dependent Variable: mc

Source	DF	Sum of Squares	Mean Square	F Value
Model	5	10.84357875	2.16871575	113.60
Error	642	12.25653212	0.01909117	
Corrected Total	647	23.10011087		

Source	Pr > F
Model	<.0001
Error	
Corrected Total	

R-Square	Coeff Var	Root MSE	mc Mean
0.469417	74.86115	0.138171	0.184569

Source	DF	Type III SS	Mean Square	F Value
RT	1	0.99099735	0.99099735	51.91
CT	2	9.56951959	4.78475980	250.63
RT*CT	2	0.28306181	0.14153091	7.41

Source	Pr > F
RT	<.0001
CT	<.0001
RT*CT	0.0007

Contrast	DF	Contrast SS	Mean Square	F Value
Linear CT	1	9.17408823	9.17408823	480.54
LinearCT@RT1	1	6.31879230	6.31879230	330.98
LinearCT@RT2	1	3.13203750	3.13203750	164.06

Contrast	Pr > F
Linear CT	<.0001
LinearCT@RT1	<.0001
LinearCT@RT2	<.0001

Split-Split pieces: RTxCT and Linear components 38
Do we have <junk33>
06:58 Wednesday, August 3, 2005

Obs	_NAME_	_SOURCE_	_TYPE_	DF	SS	F	PROB
1	mc	ERROR	ERROR	642	12.2565	.	.
2	mc	RT	SS3	1	0.9910	51.909	1.6359E-12
3	mc	CT	SS3	2	9.5695	250.627	3.589E-81
4	mc	RT*CT	SS3	2	0.2831	7.413	.000656156
5	mc	Linear CT	CONTRAST	1	9.1741	480.541	6.0981E-80
6	mc	LinearCT@RT1	CONTRAST	1	6.3188	330.980	5.865E-60
7	mc	LinearCT@RT2	CONTRAST	1	3.1320	164.057	1.3075E-33

Split-Split pieces: RTxCT and Linear components 39

Do we have <splitsplit3>
06:58 Wednesday, August 3, 2005

Obs	DF	SS	_SOURCE_
1	16	0.1754	ERRORA
2	24	0.1578	ERRORB
3	528	5.0582	ERRORC
4	642	12.2565	ERROR
5	1	0.9910	RT
6	2	9.5695	CT
7	2	0.2831	RT*CT
8	1	9.1741	Linear
9	1	6.3188	Linear
10	1	3.1320	Linear

Split-Split pieces: RT x CT and Linear contrasts 40
06:58 Wednesday, August 3, 2005

(RTxCT)SS = 0.2830618148

(RTxCT)MS = 0.1415309074

F(RTxCT) = 14.773599052 p-value = 5.7148286E-7

(RT x LinearCT)SS = 0.2767415648

(RT x LinearCT)MS = 0.2767415648

F(RT x LinCT) = 28.887463484 p-value = 1.1530006E-7

Split-Split pieces: RTxCT Quadratic components 41
06:58 Wednesday, August 3, 2005

The GLM Procedure

Class Level Information

Class	Levels	Values
RT	2	1 2
CT	3	1 2 3

Number of Observations Read 648
Number of Observations Used 648

Split-Split pieces: RTxCT Quadratic components 42
06:58 Wednesday, August 3, 2005

The GLM Procedure

Dependent Variable: mc

Source	DF	Sum of Squares	Mean Square	F Value
Model	5	10.84357875	2.16871575	113.60

Error 642 12.25653212 0.01909117

Corrected Total 647 23.10011087

Source	Pr > F
Model	<.0001
Error	
Corrected Total	

R-Square	Coeff Var	Root MSE	mc Mean
0.469417	74.86115	0.138171	0.184569

Source	DF	Type III SS	Mean Square	F Value
RT	1	0.99099735	0.99099735	51.91
CT	2	9.56951959	4.78475980	250.63
RT*CT	2	0.28306181	0.14153091	7.41

Source	Pr > F
RT	<.0001
CT	<.0001
RT*CT	0.0007

Contrast	DF	Contrast SS	Mean Square	F Value
Quadratic CT	1	0.39543136	0.39543136	20.71
QuadraticCT@RT1	1	0.15088356	0.15088356	7.90
Quadratic@RT2	1	0.25086806	0.25086806	13.14

Contrast	Pr > F
Quadratic CT	<.0001
QuadraticCT@RT1	0.0051
Quadratic@RT2	0.0003

Split-Split pieces: RTxCT Quadratic components 43
Do we have <junk34>
06:58 Wednesday, August 3, 2005

Obs	_NAME_	_SOURCE_	_TYPE_	DF	SS	F	PROB
1	mc	ERROR	ERROR	642	12.2565	.	.
2	mc	RT	SS3	1	0.9910	51.909	1.6359E-12
3	mc	CT	SS3	2	9.5695	250.627	3.589E-81
4	mc	RT*CT	SS3	2	0.2831	7.413	.000656156
5	mc	Quadratic CT	CONTRAST	1	0.3954	20.713	.000006383
6	mc	QuadraticCT@RT1	CONTRAST	1	0.1509	7.903	.005085008
7	mc	Quadratic@RT2	CONTRAST	1	0.2509	13.141	.000311867

Split-Split pieces: RTxCT Quadratic components 44
Do we have <splitsplit4>
06:58 Wednesday, August 3, 2005

Obs	DF	SS	_SOURCE_
1	16	0.1754	ERRORA
2	24	0.1578	ERRORB
3	528	5.0582	ERRORC

4	642	12.2565	ERROR
5	1	0.9910	RT
6	2	9.5695	CT
7	2	0.2831	RT*CT
8	1	0.3954	Quadra
9	1	0.1509	Quadra
10	1	0.2509	Quadra

Split-Split pieces: RT x CT Quadratic contrasts 45
06:58 Wednesday, August 3, 2005

(RT x QuadraticCT)SS = 0.00632025

(RT x QuadraticCT)MS = 0.00632025

F(RT x QuadraticCT) = 0.6597346199 p-value = 0.4170196931

Split-Split pieces: size, RT, time and Linear components 46
06:58 Wednesday, August 3, 2005

The GLM Procedure

Class Level Information

Class	Levels	Values
size	2	1 2
RT	2	1 2
time	3	1 2 3

Number of Observations Read 648
Number of Observations Used 648

Split-Split pieces: size, RT, time and Linear components 47
06:58 Wednesday, August 3, 2005

The GLM Procedure

Dependent Variable: mc

Source	DF	Sum of Squares	Mean Square	F Value
Model	11	4.32187363	0.39289760	13.31
Error	636	18.77823724	0.02952553	
Corrected Total	647	23.10011087		

Source	Pr > F
Model	<.0001
Error	
Corrected Total	

R-Square	Coeff Var	Root MSE	mc Mean

0.187093 93.09772 0.171830 0.184569

Source	DF	Type III SS	Mean Square	F Value
size	1	0.10772535	0.10772535	3.65
RT	1	0.99099735	0.99099735	33.56
size*RT	1	0.00006485	0.00006485	0.00
time	2	3.05794695	1.52897348	51.78
size*time	2	0.06970473	0.03485237	1.18
RT*time	2	0.01136203	0.00568101	0.19
size*RT*time	2	0.08407237	0.04203619	1.42

Source	Pr > F
size	0.0566
RT	<.0001
size*RT	0.9626
time	<.0001
size*time	0.3078
RT*time	0.8250
size*RT*time	0.2416

Contrast	DF	Contrast SS	Mean Square	F Value
Linear Time	1	2.98319028	2.98319028	101.04
LinT@size1	1	1.53942234	1.53942234	52.14

Split-Split pieces: size, RT, time and Linear components 48
06:58 Wednesday, August 3, 2005

The GLM Procedure

Dependent Variable: mc

Contrast	DF	Contrast SS	Mean Square	F Value
LinT@size2	1	1.44452267	1.44452267	48.92

Contrast	Pr > F
Linear Time	<.0001
LinT@size1	<.0001
LinT@size2	<.0001

Split-Split pieces: size, RT, time and Linear components 49
Do we have <junk35>
06:58 Wednesday, August 3, 2005

Obs	_NAME_	_SOURCE_	_TYPE_	DF	SS	F	PROB
1	mc	ERROR	ERROR	636	18.7782	.	.
2	mc	size	SS3	1	0.1077	3.649	0.05657
3	mc	RT	SS3	1	0.9910	33.564	0.00000
4	mc	size*RT	SS3	1	0.0001	0.002	0.96263
5	mc	time	SS3	2	3.0579	51.785	0.00000
6	mc	size*time	SS3	2	0.0697	1.180	0.30782
7	mc	RT*time	SS3	2	0.0114	0.192	0.82502
8	mc	size*RT*time	SS3	2	0.0841	1.424	0.24158
9	mc	Linear Time	CONTRAST	1	2.9832	101.038	0.00000
10	mc	LinT@size1	CONTRAST	1	1.5394	52.139	0.00000
11	mc	LinT@size2	CONTRAST	1	1.4445	48.925	0.00000

Split-Split pieces: size, RT, time and Linear components 50
Do we have <splitsplit5>
06:58 Wednesday, August 3, 2005

Obs	DF	SS	_SOURCE_
1	16	0.1754	ERRORA
2	24	0.1578	ERRORB
3	528	5.0582	ERRORC
4	636	18.7782	ERROR
5	1	0.1077	size
6	1	0.9910	RT
7	1	0.0001	size*R
8	2	3.0579	time
9	2	0.0697	size*t
10	2	0.0114	RT*tim
11	2	0.0841	size*R
12	1	2.9832	Linear
13	1	1.5394	LinT@s
14	1	1.4445	LinT@s

Split-Split pieces: size, RT, time and Linear contrasts 51
06:58 Wednesday, August 3, 2005

(Size)SS = 0.1077253472

(Size)MS = 0.1077253472

F(Size) = 11.244830664 p-value = 0.0008557463

(SizexRT)SS = 0.0000648534

(SizexRT)MS = 0.0000648534

F(SizexRT) = 0.0067696737 p-value = 0.9344568082

(SizexTime)SS = 0.0697047315

(SizexTime)MS = 0.0348523657

F(SizexTime) = 3.6380384108 p-value = 0.0269654343

(SizexRTxTime)SS = 0.0840723735

(SizexRTxTime)MS = 0.0420361867

F(SizexRTxTime) = 4.3879162493 p-value = 0.0128829597

(Size x LinearT)SS = 0.0007547245

(Size x LinearT)MS = 0.0007547245

F(Size x LinearT) = 0.0787813624 p-value = 0.7790656582

Split-Split pieces: size time quadratic components 52

06:58 Wednesday, August 3, 2005

The GLM Procedure

Class Level Information

Class	Levels	Values
size	2	1 2
time	3	1 2 3

Number of Observations Read 648
Number of Observations Used 648

Split-Split pieces: size time quadratic components 53

06:58 Wednesday, August 3, 2005

The GLM Procedure

Dependent Variable: mc

Source	DF	Sum of Squares	Mean Square	F Value
Model	5	3.23537703	0.64707541	20.91
Error	642	19.86473384	0.03094195	
Corrected Total	647	23.10011087		

Source	Pr > F
Model	<.0001
Error	
Corrected Total	

R-Square	Coeff Var	Root MSE	mc Mean
0.140059	95.30464	0.175903	0.184569

Source	DF	Type III SS	Mean Square	F Value
size	1	0.10772535	0.10772535	3.48
time	2	3.05794695	1.52897348	49.41
size*time	2	0.06970473	0.03485237	1.13

Source	Pr > F
size	0.0625
time	<.0001
size*time	0.3248

Contrast	DF	Contrast SS	Mean Square	F Value
Quadratic Time	1	0.07475667	0.07475667	2.42
QuadT@size1	1	0.00005868	0.00005868	0.00
QuadT@size2	1	0.14364800	0.14364800	4.64

Contrast	Pr > F
Quadratic Time	0.1206

QuadT@size1 0.9653
QuadT@size2 0.0316

Split-Split pieces: size time quadratic components 54
Do we have <junk36>
06:58 Wednesday, August 3, 2005

Obs	_NAME_	_SOURCE_	_TYPE_	DF	SS	F	PROB
1	mc	ERROR	ERROR	642	19.8647	.	.
2	mc	size	SS3	1	0.1077	3.4815	0.06251
3	mc	time	SS3	2	3.0579	49.4143	0.00000
4	mc	size*time	SS3	2	0.0697	1.1264	0.32484
5	mc	Quadratic Time	CONTRAST	1	0.0748	2.4160	0.12059
6	mc	QuadT@size1	CONTRAST	1	0.0001	0.0019	0.96528
7	mc	QuadT@size2	CONTRAST	1	0.1436	4.6425	0.03156

Split-Split pieces: size time quadratic components 55
Do we have <splitsplit6>
06:58 Wednesday, August 3, 2005

Obs	DF	SS	_SOURCE_
1	16	0.1754	ERRORA
2	24	0.1578	ERRORB
3	528	5.0582	ERRORC
4	642	19.8647	ERROR
5	1	0.1077	size
6	2	3.0579	time
7	2	0.0697	size*t
8	1	0.0748	Quadra
9	1	0.0001	QuadT@
10	1	0.1436	QuadT@

Split-Split pieces: Size Time Quadratic contrasts 56
06:58 Wednesday, August 3, 2005

(Size x QuadTime)SS = 0.0689500069

(Size x QuadTime)MS = 0.0689500069

F(Size x QuadTime) = 7.1972954592 p-value = 0.0075302327

Split-Split pieces: size CT Linear components 57
06:58 Wednesday, August 3, 2005

The GLM Procedure

Class Level Information

Class	Levels	Values
size	2	1 2
CT	3	1 2 3

Number of Observations Read 648
Number of Observations Used 648

Split-Split pieces: size CT Linear components 58
06:58 Wednesday, August 3, 2005

The GLM Procedure

Dependent Variable: mc

Source	DF	Sum of Squares	Mean Square	F Value
Model	5	9.70328287	1.94065657	93.00
Error	642	13.39682801	0.02086733	
Corrected Total	647	23.10011087		

Source	Pr > F
Model	<.0001
Error	
Corrected Total	

R-Square	Coeff Var	Root MSE	mc Mean
0.420054	78.26610	0.144455	0.184569

Source	DF	Type III SS	Mean Square	F Value
size	1	0.10772535	0.10772535	5.16
CT	2	9.56951959	4.78475980	229.29
size*CT	2	0.02603793	0.01301896	0.62

Source	Pr > F
size	0.0234
CT	<.0001
size*CT	0.5362

Contrast	DF	Contrast SS	Mean Square	F Value
Linear CT	1	9.17408823	9.17408823	439.64
LinCT@size1	1	4.59637538	4.59637538	220.27
LinCT@size2	1	4.57772234	4.57772234	219.37

Contrast	Pr > F
Linear CT	<.0001
LinCT@size1	<.0001
LinCT@size2	<.0001

Split-Split pieces: size CT Linear components 59
Do we have <junk37>
06:58 Wednesday, August 3, 2005

Obs	_NAME_	_SOURCE_	_TYPE_	DF	SS	F	PROB
1	mc	ERROR	ERROR	642	13.3968	.	.
2	mc	size	SS3	1	0.1077	5.162	0.02341
3	mc	CT	SS3	2	9.5695	229.294	0.00000
4	mc	size*CT	SS3	2	0.0260	0.624	0.53618
5	mc	Linear CT	CONTRAST	1	9.1741	439.639	0.00000

6	mc	LinCT@size1	CONTRAST	1	4.5964	220.267	0.00000
7	mc	LinCT@size2	CONTRAST	1	4.5777	219.373	0.00000

Split-Split pieces: size CT Linear components 60
Do we have <splitsplit7>
06:58 Wednesday, August 3, 2005

Obs	DF	SS	_SOURCE_
1	16	0.1754	ERRORA
2	24	0.1578	ERRORB
3	528	5.0582	ERRORC
4	642	13.3968	ERROR
5	1	0.1077	size
6	2	9.5695	CT
7	2	0.0260	size*C
8	1	9.1741	Linear
9	1	4.5964	LinCT@
10	1	4.5777	LinCT@

Split-Split pieces: size, CT Linear contrasts 61
06:58 Wednesday, August 3, 2005

(SizexCT)SS = 0.0260379259

(SizexCT)MS = 0.013018963

F(SizexCT) = 1.3589748162 p-value = 0.2578211833

(Size x LinearCT)SS = 9.4814815E-6

(Size x LinearCT)MS = 9.4814815E-6

F(Size x LinearCT) = 0.0009897174 p-value = 0.9749147595

Split-Split pieces: size CT quadratic components 62
06:58 Wednesday, August 3, 2005

The GLM Procedure

Class Level Information

Class	Levels	Values
size	2	1 2
CT	3	1 2 3

Number of Observations Read 648
Number of Observations Used 648

Split-Split pieces: size CT quadratic components 63
06:58 Wednesday, August 3, 2005

The GLM Procedure

Dependent Variable: mc

Source	DF	Sum of Squares	Mean Square	F Value
Model	5	9.70328287	1.94065657	93.00
Error	642	13.39682801	0.02086733	
Corrected Total	647	23.10011087		

Source	Pr > F
Model	<.0001
Error	
Corrected Total	

R-Square	Coeff Var	Root MSE	mc Mean
0.420054	78.26610	0.144455	0.184569

Source	DF	Type III SS	Mean Square	F Value
size	1	0.10772535	0.10772535	5.16
CT	2	9.56951959	4.78475980	229.29
size*CT	2	0.02603793	0.01301896	0.62

Source	Pr > F
size	0.0234
CT	<.0001
size*CT	0.5362

Contrast	DF	Contrast SS	Mean Square	F Value
Quadratic CT	1	0.39543136	0.39543136	18.95
QuadCT@size1	1	0.10927812	0.10927812	5.24
QuadCT@size2	1	0.31218168	0.31218168	14.96

Contrast	Pr > F
Quadratic CT	<.0001
QuadCT@size1	0.0224
QuadCT@size2	0.0001

Split-Split pieces: size CT quadratic components 64
Do we have <junk38>
06:58 Wednesday, August 3, 2005

Obs	_NAME_	_SOURCE_	_TYPE_	DF	SS	F	PROB
1	mc	ERROR	ERROR	642	13.3968	.	.
2	mc	size	SS3	1	0.1077	5.162	0.02341
3	mc	CT	SS3	2	9.5695	229.294	0.00000
4	mc	size*CT	SS3	2	0.0260	0.624	0.53618
5	mc	Quadratic CT	CONTRAST	1	0.3954	18.950	0.00002
6	mc	QuadCT@size1	CONTRAST	1	0.1093	5.237	0.02244
7	mc	QuadCT@size2	CONTRAST	1	0.3122	14.960	0.00012

Split-Split pieces: size CT quadratic components 65
Do we have <splitsplit8>
06:58 Wednesday, August 3, 2005

Obs	DF	SS	_SOURCE_
1	16	0.1754	ERRORA
2	24	0.1578	ERRORB
3	528	5.0582	ERRORC
4	642	13.3968	ERROR
5	1	0.1077	size
6	2	9.5695	CT
7	2	0.0260	size*C
8	1	0.3954	Quadra
9	1	0.1093	QuadCT
10	1	0.3122	QuadCT

Split-Split pieces: Size CT Quadratic contrasts 66
06:58 Wednesday, August 3, 2005

(Size x Quad CT)SS = 0.0260284444

(Size x Quad CT)MS = 0.0260284444

F(Size x Quad CT) = 2.716959915 p-value = 0.099881822

Split-Split pieces: abrade CT Linear components 67
06:58 Wednesday, August 3, 2005

The GLM Procedure

Class Level Information

Class	Levels	Values
abrade	2	1 2
CT	3	1 2 3

Number of Observations Read 648
Number of Observations Used 648

Split-Split pieces: abrade CT Linear components 68
06:58 Wednesday, August 3, 2005

The GLM Procedure

Dependent Variable: mc

Source	DF	Sum of Squares	Mean Square	F Value
Model	5	9.92971561	1.98594312	96.81
Error	642	13.17039527	0.02051463	
Corrected Total	647	23.10011087		

Source	Pr > F
Model	<.0001
Error	

Corrected Total

R-Square	Coeff Var	Root MSE	mc Mean
0.429856	77.60185	0.143229	0.184569

Source	DF	Type III SS	Mean Square	F Value
abrade	1	0.32890556	0.32890556	16.03
CT	2	9.56951959	4.78475980	233.24
abrade*CT	2	0.03129046	0.01564523	0.76

Source	Pr > F
abrade	<.0001
CT	<.0001
abrade*CT	0.4669

Contrast	DF	Contrast SS	Mean Square	F Value
Linear CT	1	9.17408823	9.17408823	447.20
LinCT@abrade1	1	5.11034341	5.11034341	249.11
LinCT@abrade2	1	4.09200417	4.09200417	199.47

Contrast	Pr > F
Linear CT	<.0001
LinCT@abrade1	<.0001
LinCT@abrade2	<.0001

Split-Split pieces: abrade CT Linear components 69
Do we have <junk39>
06:58 Wednesday, August 3, 2005

Obs	_NAME_	_SOURCE_	_TYPE_	DF	SS	F	PROB
1	mc	ERROR	ERROR	642	13.1704	.	.
2	mc	abrade	SS3	1	0.3289	16.033	0.00007
3	mc	CT	SS3	2	9.5695	233.236	0.00000
4	mc	abrade*CT	SS3	2	0.0313	0.763	0.46686
5	mc	Linear CT	CONTRAST	1	9.1741	447.197	0.00000
6	mc	LinCT@abrade1	CONTRAST	1	5.1103	249.107	0.00000
7	mc	LinCT@abrade2	CONTRAST	1	4.0920	199.468	0.00000

Split-Split pieces: abrade CT Linear components 70
Do we have <splitsplit9>
06:58 Wednesday, August 3, 2005

Obs	DF	SS	_SOURCE_
1	16	0.1754	ERRORA
2	24	0.1578	ERRORB
3	528	5.0582	ERRORC
4	642	13.1704	ERROR
5	1	0.3289	abrade
6	2	9.5695	CT
7	2	0.0313	abrade
8	1	9.1741	Linear
9	1	5.1103	LinCT@
10	1	4.0920	LinCT@

Split-Split pieces: Abrade, CT Linear contrasts 71
06:58 Wednesday, August 3, 2005

(Abrade)SS = 0.3289055571

(Abrade)MS = 0.3289055571

F(Abrade) = 34.332563222 p-value = 8.1828215E-9

(AbradexCT)SS = 0.0312904568

(AbradexCT)MS = 0.0156452284

F(AbradexCT) = 1.6331155902 p-value = 0.1963051263

(Abrade x LinearCT)SS = 0.0282593426

(Abrade x LinearCT)MS = 0.0282593426

F(Abrade x LinearCT) = 2.9498305676 p-value = 0.0864729166

Split-Split pieces: Abrade CT quadratic components 72
06:58 Wednesday, August 3, 2005

The GLM Procedure

Class Level Information

Class	Levels	Values
abrade	2	1 2
CT	3	1 2 3

Number of Observations Read 648
Number of Observations Used 648

Split-Split pieces: Abrade CT quadratic components 73
06:58 Wednesday, August 3, 2005

The GLM Procedure

Dependent Variable: mc

Source	DF	Sum of Squares	Mean Square	F Value
Model	5	9.92971561	1.98594312	96.81
Error	642	13.17039527	0.02051463	
Corrected Total	647	23.10011087		

Source	Pr > F
Model	<.0001
Error	

Corrected Total

R-Square	Coeff Var	Root MSE	mc Mean
0.429856	77.60185	0.143229	0.184569

Source	DF	Type III SS	Mean Square	F Value
abrade	1	0.32890556	0.32890556	16.03
CT	2	9.56951959	4.78475980	233.24
abrade*CT	2	0.03129046	0.01564523	0.76

Source	Pr > F
abrade	<.0001
CT	<.0001
abrade*CT	0.4669

Contrast	DF	Contrast SS	Mean Square	F Value
Quadratic CT	1	0.39543136	0.39543136	19.28
QuadCT@abrade1	1	0.16461047	0.16461047	8.02
QuadCT@abrade2	1	0.23385201	0.23385201	11.40

Contrast	Pr > F
Quadratic CT	<.0001
QuadCT@abrade1	0.0048
QuadCT@abrade2	0.0008

Split-Split pieces: Abrade CT quadratic components 74
Do we have <junk310>
06:58 Wednesday, August 3, 2005

Obs	_NAME_	_SOURCE_	_TYPE_	DF	SS	F	PROB
1	mc	ERROR	ERROR	642	13.1704	.	.
2	mc	abrade	SS3	1	0.3289	16.033	0.00007
3	mc	CT	SS3	2	9.5695	233.236	0.00000
4	mc	abrade*CT	SS3	2	0.0313	0.763	0.46686
5	mc	Quadratic CT	CONTRAST	1	0.3954	19.276	0.00001
6	mc	QuadCT@abrade1	CONTRAST	1	0.1646	8.024	0.00476
7	mc	QuadCT@abrade2	CONTRAST	1	0.2339	11.399	0.00078

Split-Split pieces: Abrade CT quadratic components 75
Do we have <splitsplit10>
06:58 Wednesday, August 3, 2005

Obs	DF	SS	_SOURCE_
1	16	0.1754	ERRORA
2	24	0.1578	ERRORB
3	528	5.0582	ERRORC
4	642	13.1704	ERROR
5	1	0.3289	abrade
6	2	9.5695	CT
7	2	0.0313	abrade
8	1	0.3954	Quadra
9	1	0.1646	QuadCT
10	1	0.2339	QuadCT

Split-Split pieces: abrade CT Quadratic contrasts 76
06:58 Wednesday, August 3, 2005

(abrade x Quad CT)SS = 0.0030311142

(abrade x Quad CT)MS = 0.0030311142

F(abrade x Quad CT) = 0.3164006128 p-value = 0.5740175495

Split-Split pieces: abrade time Linear components 77
06:58 Wednesday, August 3, 2005

The GLM Procedure

Class Level Information

Class	Levels	Values
abrade	2	1 2
time	3	1 2 3

Number of Observations Read 648
Number of Observations Used 648

Split-Split pieces: abrade time Linear components 78
06:58 Wednesday, August 3, 2005

The GLM Procedure

Dependent Variable: mc

Source	DF	Sum of Squares	Mean Square	F Value
Model	5	3.54392714	0.70878543	23.27
Error	642	19.55618373	0.03046135	
Corrected Total	647	23.10011087		

Source	Pr > F
Model	<.0001
Error	
Corrected Total	

R-Square	Coeff Var	Root MSE	mc Mean
0.153416	94.56158	0.174532	0.184569

Source	DF	Type III SS	Mean Square	F Value
abrade	1	0.32890556	0.32890556	10.80
time	2	3.05794695	1.52897348	50.19
abrade*time	2	0.15707463	0.07853732	2.58

Source	Pr > F

abrade	0.0011
time	<.0001
abrade*time	0.0767

Contrast	DF	Contrast SS	Mean Square	F Value
Linear Time	1	2.98319028	2.98319028	97.93
LinT@abrade1	1	1.66198523	1.66198523	54.56
LinT@abrade2	1	1.33041807	1.33041807	43.68

Contrast	Pr > F
Linear Time	<.0001
LinT@abrade1	<.0001
LinT@abrade2	<.0001

Split-Split pieces: abrade time Linear components 79
Do we have <junk311>
06:58 Wednesday, August 3, 2005

Obs	_NAME_	_SOURCE_	_TYPE_	DF	SS	F	PROB
1	mc	ERROR	ERROR	642	19.5562	.	.
2	mc	abrade	SS3	1	0.3289	10.7975	0.001072
3	mc	time	SS3	2	3.0579	50.1939	0.000000
4	mc	abrade*time	SS3	2	0.1571	2.5783	0.076692
5	mc	Linear Time	CONTRAST	1	2.9832	97.9336	0.000000
6	mc	LinT@abrade1	CONTRAST	1	1.6620	54.5605	0.000000
7	mc	LinT@abrade2	CONTRAST	1	1.3304	43.6756	0.000000

Split-Split pieces: abrade time Linear components 80
Do we have <splitsplit11>
06:58 Wednesday, August 3, 2005

Obs	DF	SS	_SOURCE_
1	16	0.1754	ERRORA
2	24	0.1578	ERRORB
3	528	5.0582	ERRORC
4	642	19.5562	ERROR
5	1	0.3289	abrade
6	2	3.0579	time
7	2	0.1571	abrade
8	1	2.9832	Linear
9	1	1.6620	LinT@a
10	1	1.3304	LinT@a

Split-Split pieces: Abrade, time Linear contrasts 81
06:58 Wednesday, August 3, 2005

(AbradexTime)SS = 0.1570746327

(AbradexTime)MS = 0.0785373164

F(AbradexTime) = 8.1980596587 p-value = 0.0003117382

(Abrade x LinearTime)SS = 0.0092130208

(Abrade x LinearTime)MS = 0.0092130208

F(Abrade x LinearTime) = 0.961694363 p-value = 0.3272094745

Split-Split pieces: Abrade time quadratic components 82
06:58 Wednesday, August 3, 2005

The GLM Procedure

Class Level Information

Class	Levels	Values
abrade	2	1 2
time	3	1 2 3

Number of Observations Read 648
Number of Observations Used 648

Split-Split pieces: Abrade time quadratic components 83
06:58 Wednesday, August 3, 2005

The GLM Procedure

Dependent Variable: mc

Source	DF	Sum of Squares	Mean Square	F Value
Model	5	3.54392714	0.70878543	23.27
Error	642	19.55618373	0.03046135	
Corrected Total	647	23.10011087		

Source	Pr > F
Model	<.0001
Error	
Corrected Total	

R-Square	Coeff Var	Root MSE	mc Mean
0.153416	94.56158	0.174532	0.184569

Source	DF	Type III SS	Mean Square	F Value
abrade	1	0.32890556	0.32890556	10.80
time	2	3.05794695	1.52897348	50.19
abrade*time	2	0.15707463	0.07853732	2.58

Source	Pr > F
abrade	0.0011
time	<.0001
abrade*time	0.0767

Contrast	DF	Contrast SS	Mean Square	F Value
Quadratic Time	1	0.07475667	0.07475667	2.45

QuadT@abrade1 1 0.21644545 0.21644545 7.11
QuadT@abrade2 1 0.00617284 0.00617284 0.20

Contrast Pr > F

Quadratic Time 0.1177
QuadT@abrade1 0.0079
QuadT@abrade2 0.6527

Split-Split pieces: Abrade time quadratic components 84
Do we have <junk312>
06:58 Wednesday, August 3, 2005

Obs	_NAME_	_SOURCE_	_TYPE_	DF	SS	F	PROB
1	mc	ERROR	ERROR	642	19.5562	.	.
2	mc	abrade	SS3	1	0.3289	10.7975	0.00107
3	mc	time	SS3	2	3.0579	50.1939	0.00000
4	mc	abrade*time	SS3	2	0.1571	2.5783	0.07669
5	mc	Quadratic Time	CONTRAST	1	0.0748	2.4541	0.11771
6	mc	QuadT@abrade1	CONTRAST	1	0.2164	7.1056	0.00788
7	mc	QuadT@abrade2	CONTRAST	1	0.0062	0.2026	0.65275

Split-Split pieces: Abrade time quadratic components 85
Do we have <splitsplit12>
06:58 Wednesday, August 3, 2005

Obs	DF	SS	_SOURCE_
1	16	0.1754	ERRORA
2	24	0.1578	ERRORB
3	528	5.0582	ERRORC
4	642	19.5562	ERROR
5	1	0.3289	abrade
6	2	3.0579	time
7	2	0.1571	abrade
8	1	0.0748	Quadra
9	1	0.2164	QuadT@
10	1	0.0062	QuadT@

Split-Split pieces: abrade time Quadratic contrasts 86
06:58 Wednesday, August 3, 2005

(abrade x Quad Time)SS = 0.1478616119

(abrade x Quad Time)MS = 0.1478616119

F(abrade x Quad Time) = 15.434424954 p-value = 0.0000967662

Split-Split pieces: not previously covered 87
06:58 Wednesday, August 3, 2005

The GLM Procedure

Class Level Information

Class Levels Values

CT 3 1 2 3

RT	2	1 2
time	3	1 2 3
size	2	1 2
abrade	2	1 2

Number of Observations Read	648
Number of Observations Used	648

Split-Split pieces: not previously covered 88
06:58 Wednesday, August 3, 2005

The GLM Procedure

Dependent Variable: mc

Source	DF	Sum of Squares	Mean Square	F Value
Model	71	17.11564488	0.24106542	23.20
Error	576	5.98446600	0.01038970	
Corrected Total	647	23.10011087		

Source	Pr > F
Model	<.0001
Error	
Corrected Total	

R-Square	Coeff Var	Root MSE	mc Mean
0.740933	55.22575	0.101930	0.184569

Source	DF	Type III SS	Mean Square	F Value
CT*RT*time	4	0.31712296	0.07928074	7.63
RT*size	1	0.00006485	0.00006485	0.01
CT*time*size	4	0.09967976	0.02491994	2.40
RT*time*size	2	0.08407237	0.04203619	4.05
CT*RT*size	2	0.06752731	0.03376365	3.25
CT*RT*time*size	4	0.22663151	0.05665788	5.45
RT*abrade	1	0.05304748	0.05304748	5.11
RT*time*abrade	2	0.06521597	0.03260798	3.14
CT*time*abrade	4	0.07950023	0.01987506	1.91

Source	Pr > F
CT*RT*time	<.0001
RT*size	0.9371
CT*time*size	0.0491
RT*time*size	0.0180
CT*RT*size	0.0395
CT*RT*time*size	0.0003
RT*abrade	0.0242
RT*time*abrade	0.0441
CT*time*abrade	0.1068

Split-Split pieces: not previously covered 89
06:58 Wednesday, August 3, 2005

The GLM Procedure

Dependent Variable: mc

Source	DF	Type III SS	Mean Square	F Value
CT*RT*abrade	2	0.03005875	0.01502938	1.45
CT*RT*time*abrade	4	0.17074562	0.04268640	4.11
size*abrade	1	0.07392013	0.07392013	7.11
time*size*abrade	2	0.03921406	0.01960703	1.89
RT*size*abrade	1	0.01233322	0.01233322	1.19
RT*time*size*abrade	2	0.25004530	0.12502265	12.03
CT*size*abrade	2	0.05391244	0.02695622	2.59
CT*time*size*abrade	4	0.16714869	0.04178717	4.02
CT*RT*size*abrade	2	0.00648627	0.00324314	0.31
CT*RT*time*size*abra	4	0.15174647	0.03793662	3.65

Source	Pr > F
CT*RT*abrade	0.2362
CT*RT*time*abrade	0.0027
size*abrade	0.0079
time*size*abrade	0.1524
RT*size*abrade	0.2764
RT*time*size*abrade	<.0001
CT*size*abrade	0.0756
CT*time*size*abrade	0.0032
CT*RT*size*abrade	0.7320
CT*RT*time*size*abra	0.0060

Split-Split pieces: not previously covered 90
Do we have <junk313>
06:58 Wednesday, August 3, 2005

Obs	_NAME_	_SOURCE_	_TYPE_	DF	SS	F	PROB
1	mc	ERROR	ERROR	576	5.98447	.	.
2	mc	CT*RT*time	SS3	4	0.31712	7.6307	0.00001
3	mc	RT*size	SS3	1	0.00006	0.0062	0.93705
4	mc	CT*time*size	SS3	4	0.09968	2.3985	0.04910
5	mc	RT*time*size	SS3	2	0.08407	4.0459	0.01799
6	mc	CT*RT*size	SS3	2	0.06753	3.2497	0.03950
7	mc	CT*RT*time*size	SS3	4	0.22663	5.4533	0.00026
8	mc	RT*abrade	SS3	1	0.05305	5.1058	0.02422
9	mc	RT*time*abrade	SS3	2	0.06522	3.1385	0.04409
10	mc	CT*time*abrade	SS3	4	0.07950	1.9130	0.10676
11	mc	CT*RT*abrade	SS3	2	0.03006	1.4466	0.23623
12	mc	CT*RT*time*abrade	SS3	4	0.17075	4.1085	0.00272
13	mc	size*abrade	SS3	1	0.07392	7.1148	0.00786
14	mc	time*size*abrade	SS3	2	0.03921	1.8872	0.15244
15	mc	RT*size*abrade	SS3	1	0.01233	1.1871	0.27638
16	mc	RT*time*size*abrade	SS3	2	0.25005	12.0333	0.00001
17	mc	CT*size*abrade	SS3	2	0.05391	2.5945	0.07555
18	mc	CT*time*size*abrade	SS3	4	0.16715	4.0220	0.00316
19	mc	CT*RT*size*abrade	SS3	2	0.00649	0.3121	0.73200
20	mc	CT*RT*time*size*abra	SS3	4	0.15175	3.6514	0.00599

Split-Split pieces: not previously covered 91
Do we have <splitsplit13>
06:58 Wednesday, August 3, 2005

Obs	_SOURCE_	DF	SS

1	ERROR	576	5.98447
2	CT*RT*time	4	0.31712
3	RT*size	1	0.00006
4	CT*time*size	4	0.09968
5	RT*time*size	2	0.08407
6	CT*RT*size	2	0.06753
7	CT*RT*time*size	4	0.22663
8	RT*abrade	1	0.05305
9	RT*time*abrade	2	0.06522
10	CT*time*abrade	4	0.07950
11	CT*RT*abrade	2	0.03006
12	CT*RT*time*abrade	4	0.17075
13	size*abrade	1	0.07392
14	time*size*abrade	2	0.03921
15	RT*size*abrade	1	0.01233
16	RT*time*size*abrade	2	0.25005
17	CT*size*abrade	2	0.05391
18	CT*time*size*abrade	4	0.16715
19	CT*RT*size*abrade	2	0.00649
20	CT*RT*time*size*abra	4	0.15175
21	ERRORA	16	0.17539
22	ERRORB	24	0.15780
23	ERRORC	528	5.05823

Split-Split pieces: not previously covered 92
The rest of the F and p values
06:58 Wednesday, August 3, 2005

Obs	_SOURCE_	DF	SS	MS	F	P
1	ERROR	576	5.98447	0.01039	1.0845	0.17108
2	**CT*RT*time**	**4**	**0.31712**	**0.07928**	**8.2757**	**0.00000**
3	**RT*size**	**1**	**0.00006**	**0.00006**	**0.0068**	**0.93446**
4	**CT*time*size**	**4**	**0.09968**	**0.02492**	**2.6012**	**0.03532**
5	**RT*time*size**	**2**	**0.08407**	**0.04204**	**4.3879**	**0.01288**
6	**CT*RT*size**	**2**	**0.06753**	**0.03376**	**3.5244**	**0.03016**
7	**CT*RT*time*size**	**4**	**0.22663**	**0.05666**	**5.9142**	**0.00012**
8	**RT*abrade**	**1**	**0.05305**	**0.05305**	**5.5373**	**0.01898**
9	**RT*time*abrade**	**2**	**0.06522**	**0.03261**	**3.4038**	**0.03398**
10	**CT*time*abrade**	**4**	**0.07950**	**0.01988**	**2.0746**	**0.08285**
11	**CT*RT*abrade**	**2**	**0.03006**	**0.01503**	**1.5688**	**0.20926**
12	**CT*RT*time*abrade**	**4**	**0.17075**	**0.04269**	**4.4558**	**0.00150**
13	**size*abrade**	**1**	**0.07392**	**0.07392**	**7.7161**	**0.00567**
14	**time*size*abrade**	**2**	**0.03921**	**0.01961**	**2.0467**	**0.13019**
15	**RT*size*abrade**	**1**	**0.01233**	**0.01233**	**1.2874**	**0.25704**
16	**RT*time*size*abrade**	**2**	**0.25005**	**0.12502**	**13.0504**	**0.00000**
17	**CT*size*abrade**	**2**	**0.05391**	**0.02696**	**2.8138**	**0.06088**
18	**CT*time*size*abrade**	**4**	**0.16715**	**0.04179**	**4.3619**	**0.00177**
19	**CT*RT*size*abrade**	**2**	**0.00649**	**0.00324**	**0.3385**	**0.71297**
20	**CT*RT*time*size*abra**	**4**	**0.15175**	**0.03794**	**3.9600**	**0.00355**
21	ERRORA	16	0.17539	0.01096	1.1443	0.31031
22	ERRORB	24	0.15780	0.00658	0.6863	0.86696
23	ERRORC	528	5.05823	0.00958	1.0000	0.50000

APPENDIX B

SPLIT-SPLIT PLOT ANOVA TABLES (WATER ACTIVITY AND MOISTURE CONTENT) FOR VACUUM BELT DRIED FRESH BLUEBERRIES

WATER ACTIVITY ANOVA

Source	DF	SS	F	p	
Whole Plot					
Time (DT)	2	5.716	180.08	<.0001	**
Linear DT	1	5.655	356.33	<.0001	**
Quad DT	1	0.061	3.83	0.068	
Rep	8	1.264	9.96	<.0001	**
DT*Rep (Error a)	16	0.254			
Split Plots					
RT	1	1.414	88.08	<.0001	**
RT*DT	2	0.037	1.15	0.333	
RT*LinDT	1	0.026	1.65	0.212	
RT*QuadDT	1	0.011	0.66	0.425	
Error b	24	0.385			
Split-Split Plots					
CT	2	14.410	369.14	<.0001	**
Lin CT	1	14.069	720.78	<.0001	**
Quad CT	1	0.342	17.50	<.0001	**
CT*DT	4	1.063	13.62	<.0001	**
LinCTxLinDT	1	0.398	20.39	<.0001	**
LinCTxQuadDT	1	0.443	22.72	<.0001	**
QuadCTxLinDT	1	0.113	5.77	0.017	*
QuadCTxQuadDT	1	0.109	5.59	0.018	*
CT*RT	2	0.209	5.34	0.005	**
RTxLinCT	1	0.080	4.09	0.044	*
RTxQuadCT	1	0.129	7.29	0.007	*
CT*RT*DT	4	0.562	6.63	<.0001	**
Size	1	0.069	3.54	0.061	
Size*DT	2	0.061	0.02	0.985	
Size*RT	1	0.011	0.58	0.447	
Size*CT	2	0.020	0.52	0.595	
Size*CT*RT	2	0.211	4.97	0.007	**
Size*CT*RT*DT	4	0.425	5.01	0.001	**

Continued….					
Source	DF	SS	F	p	
Abrade	1	0.279	14.29	0.000	**
Abrade*DT	2	0.185	4.75	0.009	**
AbxLinDT	1	0.009	0.47	0.493	
AbxQuadDT	1	0.176	9.02	0.003	**
Abrade*RT	1	0.073	3.44	0.064	
Abrade*RT*DT	2	0.166	3.91	0.021	*
Abrade*CT	2	0.022	0.55	0.576	
Ab*CT*DT	4	0.351	4.14	0.003	**
Ab*CT*RT*DT	4	0.494	5.82	0.000	**
Ab*Size	1	0.125	5.92	0.015	*
Ab*Size*RT*DT	2	0.274	6.46	0.002	**
Ab*Size*CT*DT	4	0.370	4.36	0.002	**
Error c	528	10.306			

Note: Error a is DT*Rep. Error b is Rep*RT+Rep*RT*DT. Error c is compiled from all interactions with Rep except for Rep*RT and Rep*RT*DT.

MOISTURE CONTENT ANOVA

Source	DF	SS	F	p	
Whole Plot					
Time (DT)	2	3.058	139.48	<.0001	**
Linear DT	1	2.983	272.14	<.0001	**
Quad DT	1	0.075	6.82	0.019	*
Rep	8	0.593	6.76	0.0006	**
DT*Rep (Error a)	16	0.175			
Split Plots					
RT	1	0.991	150.72	<.0001	**
DT*RT	2	0.011	0.86	0.434	
RT*LinDT	1	0.007	1.11	0.303	
RT*QuadDT	1	0.004	0.62	0.438	
Error b	24	0.158			
Split-Split Plots					
CT	2	9.570	499.45	<.0001	**
Lin CT	1	9.174	957.63	<.0001	**
Quad CT	1	0.395	41.28	<.0001	**
CT*Time	4	0.534	13.92	<.0001	**
LinCTxLinDT	1	0.428	44.69	<.0001	**
LinCTxQuadDT	1	0.055	5.75	0.017	*
QuadCTxLinDT	1	0.005	0.54	0.462	
QuadCTxQuadDT	1	0.045	4.17	0.030	*

Continued…. Source	DF	SS	F	p	
CT*RT	2	0.283	14.77	<.0001	**
RTxLinCT	1	0.277	28.89	<.0001	**
RTxQuadCT	1	0.006	0.66	0.417	
CT*RT*DT	4	0.317	8.28	<.0001	**
Size	1	0.108	11.24	0.001	**
Size*DT	2	0.070	3.64	0.027	*
SizexLinDT	1	0.001	0.08	0.779	
SizexQuadDT	1	0.069	7.20	0.008	**
Size*RT	1	0.000	0.01	0.934	
Size*CT	2	0.026	1.36	0.258	
SizexLinCT	1	0.000	0.00	0.975	
SizexQuadCT	1	0.026	2.72	0.100	
Size*CT*RT	2	0.068	3.52	0.030	*
Size*CT*DT	4	0.010	2.60	0.035	*
Size*RT*DT	2	0.084	4.39	0.013	
Size*CT*RT*DT	4	0.227	5.91	0.00012	**
Abrade	1	0.329	34.33	<.0001	**
Abrade*DT	2	0.157	8.20	0.003	**
AbxLinDT	1	0.009	0.96	0.327	
AbxQuadDT	1	0.148	15.43	0.000	**
Abrade*RT	1	0.053	5.54	0.019	*
Abrade*RT*DT	2	0.065	3.40	0.034	*
Abrade*CT	2	0.031	1.63	0.196	
AbxLinCT	1	0.028	2.95	0.086	
AbxQuadCT	1	0.003	0.32	0.574	
Ab*CT*DT	4	0.080	2.07	0.083	
Ab*CT*RT	2	0.030	1.57	0.209	
Ab*CT*RT*DT	4	0.171	4.46	0.002	**
Ab*Size	1	0.074	7.72	0.006	**
Ab*Size*DT	2	0.039	2.05	0.130	
Ab*Size*CT	2	0.054	2.81	0.061	
Ab*Size*RT*DT	2	0.250	13.05	0.000	**
Ab*Size*RT	1	0.012	1.29	0.257	
Ab*Size*CT*DT	4	0.167	4.36	0.002	**
Ab*Size*CT*RT	2	0.006	0.34	0.713	
Ab*Size*CT*RT*DT	4	0.152	3.96	0.004	**
Error c	528	5.058			
Total	647	23.100			

Note: Error a is DT*Rep. Error b is Rep*RT+Rep*RT*DT. Error c is compiled from all interactions with Rep except for Rep*RT and Rep*RT*DT.

APPENDIX C

SAS 9.1 PROGRAM AND OUTPUT FOR MEANS CALCULATION OF MOISTURE CONTENT OF VACUUM BELT DRIED BLUEBERRIES USING A SPLIT-SPLIT PLOT FACTORIAL DESIGN

The following SAS program calculates the mean values for the moisture content of the vacuum belt dried fresh refrigerated blueberries. A split-split plot factorial design was implemented for determining treatment combinations and better understanding the impacts of various factors on the drying of the blueberries. Factors included blueberry size (‘large’ and ‘small’), blueberry pretreatment (mechanical abrasion, abraded, or no treatment, non-abraded), six drying temperature combinations (two radiation temperatures, RT, of 100 °C and 120 °C combined with three conduction temperatures, CT, of 90 °C, 110 °C, and 130 °C), and three time periods (90, 105, and 120 min). The increments between temperatures (20 °C) and time (15 min) were selected to allow testing for Linear and Quadratic trends, which require even increments to be the same between all levels. The design was split by time and radiation temperature, hence a split-split plot. The first split, time, was due to the vacuum belt dryer being limited to one drying time period. The second split, radiation temperature, was because the dryer design had one radiation heating plate expanding over the three conduction heating plates. Thus, for each drying run, either 100 °C or 120 °C was set for the radiation heat plate. Radiation temperature was a qualitative factor with two levels while time and conduction temperature were quantitative due to having three levels. Moisture content and water activity were measured for each dried sample

combination of blueberries and means were calculated by SAS. The SAS program and output are included below.

PROGRAM

```
/* Split-Split Plot Design... */

dm 'output; clear; log; clear';
options ls=72 ps=55 pageno=1 formdlim=' ';
title 'Split-Split Plot Statistical Analysis of Fresh Blueberry Final MC';
title1 'Batch Vacuum-belt Drying Analysis June 06 2010';
data one;
do time=1 to 3;
      do RT=1 to 2;
            do CT=1 to 3;
                  do size=1 to 2;
                        do abrade=1 to 2;
                              do rep=1 to 9;

input mc@@;
output;
end;
end;
end;
end;
end;
end;


cards;
0.560 0.466 0.481 0.535 0.528 0.595 0.622 0.315 0.445 0.512 0.614 0.365
0.330 0.472 0.449 0.420 0.393 0.341 0.622 0.610 0.640 0.604 0.597 0.628
0.605 0.538 0.581 0.631 0.667 0.589 0.265 0.343 0.470 0.376 0.330 0.260
0.570 0.360 0.491 0.484 0.451 0.481 0.062 0.106 0.124 0.175 0.357 0.330
0.246 0.168 0.218 0.468 0.366 0.376 0.300 0.287 0.094 0.435 0.557 0.546
0.246 0.364 0.326 0.283 0.277 0.066 0.452 0.070 0.284 0.185 0.240 0.177
0.085 0.172 0.220 0.310 0.093 0.300 0.223 0.293 0.380 0.011 0.000 0.015
0.093 0.012 0.019 0.000 0.000 0.000 0.402 0.341 0.168 0.170 0.233 0.135
0.251 0.218 0.218 0.046 0.190 0.215 0.272 0.350 0.283 0.005 0.035 0.008
0.560 0.341 0.327 0.625 0.595 0.569 0.226 0.355 0.192 0.501 0.461 0.255
0.388 0.346 0.523 0.560 0.481 0.398 0.514 0.622 0.588 0.556 0.543 0.607
0.378 0.576 0.525 0.296 0.379 0.396 0.398 0.324 0.129 0.320 0.320 0.320
0.445 0.226 0.260 0.040 0.115 0.000 0.008 0.019 0.045 0.470 0.379 0.301
0.315 0.144 0.192 0.005 0.115 0.013 0.455 0.389 0.398 0.383 0.389 0.238
0.138 0.076 0.154 0.045 0.238 0.277 0.147 0.218 0.092 0.169 0.169 0.169
0.009 0.000 0.000 0.010 0.003 0.000 0.006 0.006 0.007 0.002 0.000 0.000
0.093 0.151 0.077 0.015 0.010 0.005 0.220 0.148 0.076 0.027 0.042 0.039
0.092 0.092 0.092 0.251 0.249 0.076 0.124 0.109 0.109 0.000 0.000 0.000
0.487 0.433 0.496 0.372 0.508 0.341 0.245 0.429 0.112 0.536 0.507 0.437
0.641 0.523 0.486 0.652 0.484 0.515 0.425 0.713 0.476 0.412 0.406 0.208
0.578 0.605 0.520 0.330 0.367 0.212 0.209 0.411 0.228 0.153 0.331 0.254
0.021 0.209 0.090 0.227 0.067 0.027 0.392 0.342 0.330 0.098 0.290 0.249
0.030 0.289 0.055 0.025 0.038 0.022 0.166 0.173 0.374 0.187 0.249 0.225
0.176 0.039 0.188 0.225 0.369 0.247 0.036 0.129 0.241 0.027 0.099 0.104
0.025 0.038 0.002 0.003 0.074 0.009 0.019 0.025 0.023 0.015 0.010 0.016
0.244 0.182 0.072 0.014 0.012 0.013 0.002 0.001 0.006 0.008 0.018 0.010
```

```
0.079 0.033 0.034 0.000 0.000 0.002 0.009 0.005 0.009 0.006 0.000 0.018
0.321 0.601 0.293 0.227 0.257 0.247 0.076 0.200 0.175 0.273 0.211 0.399
0.297 0.300 0.475 0.303 0.136 0.228 0.527 0.322 0.239 0.157 0.285 0.265
0.241 0.157 0.101 0.472 0.301 0.218 0.349 0.205 0.485 0.394 0.501 0.416
0.167 0.231 0.463 0.015 0.035 0.010 0.012 0.055 0.013 0.093 0.039 0.147
0.018 0.024 0.015 0.000 0.006 0.019 0.053 0.010 0.009 0.196 0.190 0.079
0.003 0.005 0.002 0.095 0.059 0.008 0.057 0.229 0.012 0.019 0.000 0.035
0.077 0.004 0.007 0.004 0.004 0.007 0.004 0.005 0.010 0.004 0.005 0.000
0.008 0.007 0.009 0.023 0.061 0.055 0.037 0.063 0.063 0.045 0.006 0.023
0.000 0.090 0.074 0.005 0.000 0.014 0.173 0.235 0.248 0.000 0.000 0.006
0.211 0.220 0.124 0.385 0.369 0.321 0.191 0.499 0.129 0.254 0.232 0.502
0.067 0.052 0.042 0.109 0.019 0.125 0.540 0.478 0.571 0.532 0.422 0.529
0.281 0.102 0.061 0.627 0.333 0.373 0.238 0.308 0.463 0.526 0.564 0.637
0.279 0.306 0.366 0.010 0.011 0.033 0.128 0.128 0.128 0.026 0.008 0.006
0.047 0.017 0.156 0.014 0.017 0.042 0.209 0.142 0.456 0.121 0.227 0.220
0.060 0.066 0.031 0.012 0.032 0.065 0.068 0.070 0.179 0.030 0.050 0.024
0.069 0.028 0.045 0.006 0.054 0.007 0.000 0.000 0.000 0.013 0.033 0.052
0.000 0.000 0.000 0.000 0.000 0.015 0.000 0.000 0.025 0.008 0.043 0.006
0.004 0.005 0.040 0.005 0.011 0.013 0.007 0.012 0.010 0.000 0.013 0.007
0.231 0.255 0.398 0.228 0.242 0.215 0.010 0.001 0.010 0.100 0.115 0.295
0.016 0.027 0.129 0.036 0.021 0.149 0.380 0.438 0.414 0.316 0.061 0.172
0.076 0.049 0.111 0.016 0.011 0.034 0.007 0.014 0.017 0.028 0.038 0.032
0.107 0.124 0.111 0.013 0.009 0.026 0.001 0.000 0.000 0.063 0.030 0.032
0.259 0.099 0.052 0.000 0.000 0.000 0.062 0.090 0.073 0.007 0.027 0.033
0.017 0.141 0.070 0.013 0.022 0.012 0.087 0.047 0.163 0.000 0.000 0.011
0.008 0.013 0.017 0.008 0.004 0.007 0.013 0.012 0.014 0.005 0.000 0.001
0.009 0.014 0.017 0.005 0.006 0.004 0.100 0.115 0.295 0.187 0.100 0.230
0.000 0.000 0.000 0.000 0.001 0.007 0.032 0.001 0.089 0.000 0.000 0.000

;
/*proc print; run; /*Yes*/
proc glm data=one outstat=junk1;
class rep abrade size CT RT time;
model mc=time|RT|CT|size|abrade|rep /ss3;
means time RT CT size abrade time*RT time*CT time*size time*abrade RT*CT RT*size
RT*abrade
CT*size CT*abrade size*abrade;
run;
```

OUTPUT

Batch Vacuum-belt Drying Analysis June 06 2010 1

The GLM Procedure

Class Level Information

Class	Levels	Values
rep	9	1 2 3 4 5 6 7 8 9

abrade	2	1 2
size	2	1 2
CT	3	1 2 3
RT	2	1 2
time	3	1 2 3

Number of Observations Read	648
Number of Observations Used	648

The GLM Procedure

Dependent Variable: mc

Source	DF	Sum of Squares	Mean Square	F Value
Model	647	23.10011087	0.03570342	.
Error	0	0.00000000	.	
Corrected Total	647	23.10011087		

Source	Pr > F
Model	.
Error	
Corrected Total	

R-Square	Coeff Var	Root MSE	mc Mean
1.000000	.	.	0.184569

Source	DF	Type III SS	Mean Square	F Value
time	2	3.05794695	1.52897348	.
RT	1	0.99099735	0.99099735	.
RT*time	2	0.01136203	0.00568101	.
CT	2	9.56951959	4.78475980	.
CT*time	4	0.53354509	0.13338627	.

CT*RT	2	0.28306181	0.14153091	.
CT*RT*time	4	0.31712296	0.07928074	.
size	1	0.10772535	0.10772535	.
size*time	2	0.06970473	0.03485237	.

Source	Pr > F
time	.
RT	.
RT*time	.
CT	.
CT*time	.
CT*RT	.
CT*RT*time	.
size	.
size*time	.

Source	DF	Type III SS	Mean Square	F Value
size*RT	1	0.00006485	0.00006485	.
size*RT*time	2	0.08407237	0.04203619	.
size*CT	2	0.02603793	0.01301896	.
size*CT*time	4	0.09967976	0.02491994	.
size*CT*RT	2	0.06752731	0.03376365	.
size*CT*RT*time	4	0.22663151	0.05665788	.
abrade	1	0.32890556	0.32890556	.
abrade*time	2	0.15707463	0.07853732	.
abrade*RT	1	0.05304748	0.05304748	.
abrade*RT*time	2	0.06521597	0.03260798	.
abrade*CT	2	0.03129046	0.01564523	.
abrade*CT*time	4	0.07950023	0.01987506	.
abrade*CT*RT	2	0.03005875	0.01502938	.
abrade*CT*RT*time	4	0.17074562	0.04268640	.
abrade*size	1	0.07392012	0.07392012	.
abrade*size*time	2	0.03921406	0.01960703	.
abrade*size*RT	1	0.01233322	0.01233322	.
abrade*size*RT*time	2	0.25004530	0.12502265	.
abrade*size*CT	2	0.05391244	0.02695622	.
abrade*size*CT*time	4	0.16714869	0.04178717	.
abrade*size*CT*RT	2	0.00648627	0.00324314	.
abra*size*CT*RT*time	4	0.15174647	0.03793662	.
rep	8	0.59303589	0.07412949	.
rep*time	16	0.17539207	0.01096200	.
rep*RT	8	0.04765189	0.00595649	.
rep*RT*time	16	0.11015228	0.00688452	.
rep*CT	16	0.21251552	0.01328222	.

rep*CT*time	32	0.14770788	0.00461587 .
rep*CT*RT	16	0.07655007	0.00478438 .
rep*CT*RT*time	32	0.32043823	0.01001369 .
rep*size	8	0.01751239	0.00218905 .
rep*size*time	16	0.06471191	0.00404449 .
rep*size*RT	8	0.03432888	0.00429111 .
rep*size*RT*time	16	0.18436043	0.01152253 .
rep*size*CT	16	0.23717780	0.01482361 .
rep*size*CT*time	32	0.31541727	0.00985679 .
rep*size*CT*RT	16	0.08398408	0.00524901 .
rep*size*CT*RT*time	32	0.26423419	0.00825732 .
rep*abrade	8	0.09216240	0.01152030 .
rep*abrade*time	16	0.20794545	0.01299659 .
rep*abrade*RT	8	0.08593336	0.01074167 .
rep*abrade*RT*time	16	0.05839506	0.00364969 .
rep*abrade*CT	16	0.27501538	0.01718846 .
rep*abrade*CT*time	32	0.57157102	0.01786159 .
rep*abrade*CT*RT	16	0.09294086	0.00580880 .
rep*abrad*CT*RT*time	32	0.32364152	0.01011380 .

Source	Pr > F
size*RT	.
size*RT*time	.
size*CT	.
size*CT*time	.
size*CT*RT	.
size*CT*RT*time	.
abrade	.
abrade*time	.
abrade*RT	.
abrade*RT*time	.
abrade*CT	.
abrade*CT*time	.
abrade*CT*RT	.
abrade*CT*RT*time	.
abrade*size	.
abrade*size*time	.
abrade*size*RT	.
abrade*size*RT*time	.
abrade*size*CT	.
abrade*size*CT*time	.
abrade*size*CT*RT	.
abra*size*CT*RT*time	.
rep	.
rep*time	.

rep*RT	.
rep*RT*time	.
rep*CT	.
rep*CT*time	.
rep*CT*RT	.
rep*CT*RT*time	.
rep*size	.
rep*size*time	.
rep*size*RT	.
rep*size*RT*time	.
rep*size*CT	.
rep*size*CT*time	.
rep*size*CT*RT	.
rep*size*CT*RT*time	.
rep*abrade	.
rep*abrade*time	.
rep*abrade*RT	.
rep*abrade*RT*time	.
rep*abrade*CT	.
rep*abrade*CT*time	.
rep*abrade*CT*RT	.
rep*abrad*CT*RT*time	.

Source	DF	Type III SS	Mean Square	F Value
rep*abrade*size	8	0.02491178	0.00311397	.
rep*abrade*size*time	16	0.18943807	0.01183988	.
rep*abrade*size*RT	8	0.03117812	0.00389727	.
rep*abr*size*RT*time	16	0.10940490	0.00683781	.
rep*abrade*size*CT	16	0.12517678	0.00782355	.
rep*abr*size*CT*time	32	0.22983318	0.00718229	.
rep*abrad*size*CT*RT	16	0.12027517	0.00751720	.
re*abr*siz*CT*RT*tim	32	0.56147217	0.01754601	.

Source	Pr > F
rep*abrade*size	.
rep*abrade*size*time	.
rep*abrade*size*RT	.
rep*abr*size*RT*time	.
rep*abrade*size*CT	.
rep*abr*size*CT*time	.
rep*abrad*size*CT*RT	.
re*abr*siz*CT*RT*tim	.

Level of time	N	mc Mean	mc Std Dev
1	216	0.27526389	0.19729508
2	216	0.16937963	0.17807629
3	216	0.10906481	0.15027592

Level of RT	N	mc Mean	mc Std Dev
1	324	0.22367593	0.20166105
2	324	0.14546296	0.16667960

Level of CT	N	mc Mean	mc Std Dev
1	216	0.34776389	0.18498152
2	216	0.14963426	0.14475792
3	216	0.05631019	0.08809066

Level of size	N	mc Mean	mc Std Dev
1	324	0.17167593	0.18622528
2	324	0.19746296	0.19106020

Level of abrade	N	mc Mean	mc Std Dev
1	324	0.20709877	0.19772603
2	324	0.16204012	0.17721034

Level of RT	Level of time	N	mc Mean	mc Std Dev
1	1	108	0.32025000	0.19036802
1	2	108	0.20493519	0.19596458
1	3	108	0.14584259	0.17954585
2	1	108	0.23027778	0.19465142
2	2	108	0.13382407	0.15087928
2	3	108	0.07228704	0.10202721

Level of CT	Level of time	N	mc Mean	mc Std Dev
1	1	72	0.46240278	0.13037634
1	2	72	0.35688889	0.14826219
1	3	72	0.22400000	0.18892819
2	1	72	0.25358333	0.15441737
2	2	72	0.11775000	0.11757260
2	3	72	0.07756944	0.09236773
3	1	72	0.10980556	0.11522539
3	2	72	0.03350000	0.05603897
3	3	72	0.02562500	0.05192965

Level of size	Level of time	N	mc Mean	mc Std Dev
1	1	108	0.25639815	0.20444870
1	2	108	0.17107407	0.18593108
1	3	108	0.08755556	0.11802743
2	1	108	0.29412963	0.18893578
2	2	108	0.16768519	0.17071185
2	3	108	0.13057407	0.17467782

Level of abrade	Level of time	N	mc Mean	mc Std Dev
1	1	108	0.31309259	0.21075483
1	2	108	0.17054630	0.17853848
1	3	108	0.13765741	0.15546218
2	1	108	0.23743519	0.17580705
2	2	108	0.16821296	0.17843756
2	3	108	0.08047222	0.13984962

Level of CT	Level of RT	N	mc Mean	mc Std Dev
1	1	108	0.40997222	0.16991903
1	2	108	0.28555556	0.17908534
2	1	108	0.19315741	0.15099596
2	2	108	0.10611111	0.12442603
3	1	108	0.06789815	0.10307841
3	2	108	0.04472222	0.06852898

Level of size	Level of RT	N	mc Mean	mc Std Dev

1	1	162	0.21109877	0.19670150
1	2	162	0.13225309	0.16660133
2	1	162	0.23625309	0.20634227
2	2	162	0.15867284	0.16622143

Level of abrade	Level of RT	N	mc Mean	mc Std Dev
1	1	162	0.25525309	0.20481075
1	2	162	0.15894444	0.17838180
2	1	162	0.19209877	0.19399197
2	2	162	0.13198148	0.15346307

Level of size	Level of CT	N	mc Mean	mc Std Dev
1	1	108	0.33053704	0.17757465
1	2	108	0.14570370	0.15402793
1	3	108	0.03878704	0.07384007
2	1	108	0.36499074	0.19137474
2	2	108	0.15356481	0.13546129
2	3	108	0.07383333	0.09757168

Level of abrade	Level of CT	N	mc Mean	mc Std Dev
1	1	108	0.37685185	0.18426453
1	2	108	0.17522222	0.15979486
1	3	108	0.06922222	0.09607837
2	1	108	0.31867593	0.18191940
2	2	108	0.12404630	0.12348857
2	3	108	0.04339815	0.07761984

Level of abrade	Level of size	N	mc Mean	mc Std Dev
1	1	162	0.18352469	0.18826030
1	2	162	0.23067284	0.20463058
2	1	162	0.15982716	0.18398544
2	2	162	0.16425309	0.17070902

APPENDIX D

SPLIT-SPLIT PLOT SAS 9.1 PROGRAM AND OUTPUT FOR THE WATER ACTIVITY OF VACUUM BELT DRIED FROZEN BLUEBERRIES

Substantial effort went into writing the following split-split plot SAS program to generate the correct values, which were then used to generate the ANOVA table. This program differs from Appendix A due to time having only two levels for drying of frozen blueberries. Appendix A had three levels of time for the drying of fresh refrigerated blueberries. Frozen (IQF) blueberries were separated into two sizes (‘large’ and ‘small’) and were either untreated or pretreated via mechanical abrasion, abraded. Berries were vacuum belt dried at six temperature combinations (two radiation temperatures, 100 °C and 120 °C, combined with three conduction temperatures, 90 °C, 110 °C, and 130 °C) for two drying time periods (90 and 105 min). Drying was originally going to include another time period of 120 min to compare to the fresh blueberry study, but berries were burned and quality was not acceptable. The temperature increment (20 °C) was designed to allow testing for Linear and Quadratic trends, which require consistent increments between the levels. The design was split by time and radiation temperature. The first split, time, was due to the vacuum belt dryer being capable of running for only one drying time period due to difficulty of releasing and pulling vacuum during drying. Thus all samples were removed from the dryer at the same time. The second split, radiation temperature, was a result of dryer design having one radiation heating plate expanding over the three conduction heating plates. Thus, for each drying run, either 100 °C or 120 °C was set for the radiation heat plate. Radiation temperature and time were qualitative with only two levels while conduction

temperature was quantitative due to having three levels. Moisture content and water activity were measured for each dried sample combination of blueberries and analyzed in the split-split plot SAS program to determine the effects of drying time, conduction temperature, radiation temperature, abrasion, and berry size on the moisture content and water activity (with each replication being randomly allocated to the split-split plot design). The program was written to consider either water activity or moisture content. The following program includes the moisture content data on a wet basis (with values between 0 and 1, not as a percentage).

PROGRAM FOR WATER ACTIVITY

```
/* Split-Split Plot Design... */

dm 'output; clear; log; clear';
options ls=72 ps=55 pageno=1 formdlim=' ';
title 'Split-Split Plot Statistical Analysis of Frozen Blueberry Final Aw';
title1 'Batch Vacuum-belt Drying Analysis 23 May 2010';
data one;
do time=1 to 2;
        do RT=1 to 2;
                do CT=1 to 3;
                        do size=1 to 2;
                                do abrade=1 to 2;
                                        do rep=1 to 6;

input aw@@;
output;
end;
end;
end;
end;
end;
end;


cards;
0.851 0.946 0.779 0.435 0.659 0.224 0.817 0.722 0.768 0.491 0.373 0.344
0.714 0.602 0.637 0.647 0.447 0.791 0.842 0.602 0.695 0.587 0.668 0.404
0.735 0.868 0.582 0.515 0.433 0.348 0.264 0.431 0.227 0.797 0.905 0.905
0.36 0.472 0.5 0.375 0.374 0.339 0.539 0.471 0.563 0.209 0.621 0.256
0.255 0.264 0.287 0.137 0.154 0.144 0.349 0.259 0.32 0.218 0.239 0.222
0.311 0.38 0.314 0.301 0.199 0.205 0.34 0.377 0.569 0.199 0.165 0.15
0.432 0.86 0.75 0.781 0.658 0.592 0.927 0.949 0.91 0.694 0.452 0.678
0.861 0.706 0.27 0.74 0.456 0.66 0.854 0.886 0.887 0.624 0.532 0.788
0.31 0.239 0.27 0.198 0.156 0.533 0.383 0.309 0.276 0.212 0.197 0.142
0.300 0.291 0.294 0.366 0.280 0.342 0.25 0.696 0.408 0.168 0.184 0.163
0.263 0.233 0.222 0.266 0.241 0.265 0.218 0.239 0.222 0.143 0.168 0.166
0.539 0.257 0.269 0.261 0.235 0.279 0.215 0.191 0.201 0.408 0.733 0.735
```

```
0.716 0.391 0.35 0.508 0.44 0.277 0.666 0.366 0.472 0.166 0.166 0.831
0.404 0.488 0.567 0.467 0.62 0.262 0.299 0.199 0.679 0.307 0.418 0.664
0.205 0.351 0.247 0.379 0.148 0.509 0.763 0.849 0.766 0.149 0.155 0.158
0.257 0.309 0.291 0.203 0.188 0.192 0.229 0.253 0.239 0.222 0.487 0.57
0.296 0.279 0.272 0.205 0.201 0.231 0.269 0.314 0.33 0.201 0.251 0.322
0.222 0.216 0.207 0.221 0.227 0.224 0.502 0.255 0.244 0.178 0.18 0.172
0.603 0.686 0.744 0.434 0.202 0.189 0.348 0.964 0.536 0.172 0.176 0.223
0.953 0.532 0.955 0.675 0.319 0.451 0.284 0.264 0.27 0.184 0.325 0.195
0.275 0.276 0.259 0.171 0.176 0.263 0.717 0.579 0.57 0.19 0.206 0.305
0.183 0.245 0.183 0.245 0.192 0.185 0.197 0.18 0.245 0.158 0.269 0.167
0.273 0.266 0.257 0.196 0.185 0.189 0.263 0.266 0.3 0.264 0.225 0.202
0.223 0.219 0.258 0.174 0.169 0.164 0.211 0.331 0.645 0.169 0.175 0.157
;
/*proc print; run; /*Yes by Laura 23May 2010*/
proc glm data=one outstat=junk1;
class rep abrade size CT RT time;
model aw=time|RT|CT|size|abrade|rep /ss3;
means time RT CT size abrade;
run;

data two;
set junk1;
keep _SOURCE_ DF SS;
output;
proc print data=two;
title 'RT qual, Time qualitative; SOURCE, DF & SS data only....contrasts';
run;


/*To find Error a/b/c SS and DFs */
data two2; set two;
proc iml;
use two2;
read all var {DF SS} into P;
ER=J(3,2,0);
/*Error terms, col1=df, col2=SS; row1-2-3=Error(a)-(b)-(c) */
ER[1,1]=P[34,1]; ER[1,2]=P[34,2];
ER[2,1]=P[35,1]+P[36,1]; ER[2,2]=P[35,2]+P[36,2];
EC=J(28,2,0); /*To collect all 28 rep*effects for Error(c) */
EC[1:28,1:2]=P[37:64,1:2];
ER[3,1]=EC[+,1]; ER[3,2]=EC[+,2]; /*sum over rows of EC */
print ER EC; /*OK by Laura 23 May 2010*/
varnames={DF SS};
create outER from ER (|colname=varnames|);
append from ER;
run;

data ER; set outER;          /*This ER dataset has ErrorSSa/b/c */
if _N_ = 1 then _SOURCE_ = 'ERRORA';
if _N_ = 2 then _SOURCE_ = 'ERRORB';
if _N_ = 3 then _SOURCE_ = 'ERRORC';
output; run;
data two2;
set two ER;
proc print data=two2;
title "Is this two2"; run; /*OK by Laura 23 May 2010*/
```

```
/*WHOLE PLOTS part */
proc glm data=one outstat=junk1;
title1 "Whole Plot pieces: Time and reps";
class time rep;
model aw=time|rep /ss3;
run;

proc print data=junk1;
title2 "Do we have <junk1>"; run; /*Yes Laura 23 May 2010*/

/*Find Time, Rep */
data wholeplot;
set ER junk1;  /*merge Error a/b/c dataset with junk1 */
keep _SOURCE_ DF SS;
proc print;
title2 "Do we have <wholeplot>"; run; /*Yes Laura 23May2010*/
run;
title2 ' ';
data wholeplot; set wholeplot end=last;
title1 "Whole Plot pieces: Time, Rep";
retain div dfE dfT dfrep time rep Trep 0;
if _N_ = 1 then dfE=DF; else dfE=dfE+0;      /*This is Error(a) */
if _N_ = 1 then div=SS/DF; else div=div+0;
if _N_ = 5 then dfT=DF; else dfT=dfT+0; /*df for time */
if _N_ = 6 then dfrep=DF; else dfrep=dfrep+0; /*df for rep */
if _N_ = 5 then time=SS; else time=time+0; /* Time SS */
if _N_ = 6 then rep=SS; else rep=rep+0; /*rep SS */
if _N_ < 8 then SS=0;
if last then do;
 /*to find F and p-values for Time, Rep */
 timeMS=time/dfT;    /* time MS */
 Ftime=timeMS/div; ptime=1-probf(Ftime,dfT,dfE); /* Time F-, p- values*/
 repMS=rep/dfrep;
 Frep=repMS/div; prep=1-probf(Frep,dfrep,dfE);
 file print;
 put ///'     (time)SS = ' time;
 put / '      (time)MS = ' timeMS;
 put /'      F(time) = ' Ftime 'p-value = ' ptime;
 put ///'     (rep)SS = ' rep;
 put / '      (rep)MS = ' repMS;
 put /'      F(rep) = ' Frep 'p-value = ' prep;
 output;
end;
run;

/*SPLIT-PLOT part */
proc glm data=one outstat=junk2;
title1 "Split plot pieces: RT, RTxTime";
class RT time;
model aw=RT|time/ss3;
run;

proc print data=junk2;
title "Do we have <junk2>"; run; /*Yes by Laura 23May2010*/
```

```
/*Find RT, RT x Time */
data split1;
set ER junk2;  /*merge Error a/b/c dataset with junk2 */
keep _SOURCE_ DF SS;
proc print;
title2 "Do we have <split1>"; run; /*Yes Laura 23May2010*/
run;
title2 ' ';
data split1; set split1 end=last;
title1 "Split Plot pieces: RT, RT*Time and Linear contrasts";
retain div dfE dfRT dfRTtime RT RTtime RTLinT 0;
if _N_ = 2 then dfE=DF; else dfE=dfE+0;      /*This is Error(b) */
if _N_ = 2 then div=SS/DF; else div=div+0;
if _N_ = 5 then dfRT=DF; else dfRT=dfRT+0;
if _N_ = 7 then dfRTtime=DF; else dfRTtime=dfRTtime+0; /*df for RTxTime */
if _N_ = 5 then RT=SS; else RT=RT+0; /* RT SS */
if _N_ = 7 then RTtime=SS; else RTtime=RTtime+0; /*RTxTime SS */
if _N_ < 8 then SS=0;
if last then do;
  /*to find F and p-values for RT, RTxTime */
  RTMS=RT/dfRT;    /* RT MS */
  FRT=RTMS/div; pRT=1-probf(FRT,dfRT,dfE); /* RT F-, p- values*/
  RTtimeMS=RTtime/dfRTtime;
  FRTtime=RTtimeMS/div; pRTtime=1-probf(FRTtime,dfRTtime,dfE);
  file print;
  put ///'     (RT)SS = ' RT;
  put / '      (RT)MS = ' RTMS;
  put /'      F(RT) = ' FRT 'p-value = ' pRT;
  put ///'     (RTxTime)SS = ' RTtime;
  put / '      (RTxTime)MS = ' RTtimeMS;
  put /'      F(RTxTime) = ' FRTtime 'p-value = ' pRTtime;
  output;
end;
run;

/* SPLIT-SPLIT-PLOT part (Will do this in pieces, to try to avoid mistakes in using the outstat datasets-pull
together results at end */
proc glm data=one outstat=junk3;
title1 "Split-Split pieces: CT, and CT contrasts";
class CT;
model aw=CT/ss3;
contrast "Linear CT" CT -1 0 1;
contrast "Quad CT" CT -1 2 -1;
run;
proc print data=junk3;
title2 "Do we have <junk3>"; run; /*Yes by Laura 22May2010*/

data splitsplit;
set ER junk3; /*merge Error a/b/c dataset with junk3 */
keep _SOURCE_ DF SS;
proc print;
title2 "Do we have <splitsplit>"; run; /*Yes by Laura 22May2010*/
run; title2 ' ';
data splitsplit; set splitsplit end=last;
title1 "Split-Split pieces: CT, and CT contrasts";
```

```
retain div dfE dfCT CT LinCT QuadCT 0;
if _N_ = 3 then dfE=DF; else dfE=dfE+0;      /*This is Error(c) */
if _N_ = 3 then div=SS/DF; else div=div+0;
if _N_ = 5 then dfCT=DF; else dfCT=dfCT+0;   /*CT df */
if _N_ = 5 then CT = SS; else CT=CT+0;  /* CT SS */
if _N_ = 6 then LinCT=SS; else LinCT=LinCT+0;
if _N_ = 7 then QuadCT=SS; else QuadCT=QuadCT+0;
if last then do;
  /*to find F and p-values for CT, Lin/Quad CT */
  CTMS=CT/dfCT;
  FCT=CTMS/div; pCT=1-probf(FCT,dfCT,dfE);
  LinCTMS=LinCT; QuadCTMS=QuadCT; /* df=1 here */
  FLinCT=LinCTMS/div; pLinCT=1-probf(FLinCT,1,dfE);
  FQuadCT=QuadCTMS/div; pQuadCT=1-probf(FQuadCT,1,dfE);
  file print;
  put ///'     (CT)SS = ' CT;
  put / '      (CT)MS = ' CTMS;
  put /'      F(CT) = ' FCT 'p-value = ' pCT;
  put ///'     (Linear CT)SS = ' LinCT;
  put / '      (Linear CT)MS = ' LinCTMS;
  put /'      F(LinCT) = ' FLinCT 'p-value = ' pLinCT;
  put ///'     (Quad CT)SS = ' QuadCT;
  put / '      (Quad CT)MS = ' QuadCTMS;
  put /'      F(Quad CT) = ' FQuadCT 'p-value = ' pQuadCT;
  output;
end;
run; /*Yes by Laura 23May2010*/

/*CT x Time pieces */
proc glm data=one outstat=junk33;
title1 "Split-Split pieces: TimexCT and Linear components";
class time CT;
model aw=time|CT/ss3;
contrast "Linear CT" CT -1 0 1;
contrast "LinearCT@Time1" CT -1 0 1 time*CT -1 0 1;
contrast "LinearCT@Time2" CT -1 0 1 time*CT 0 0 0 -1 0 1;
run;

proc print data=junk33;
title2 "Do we have <junk33>"; run; /*Yes by Laura 23May2010*/

/*Find Time x LinearCT Contrast*/
data splitsplit3;
set ER junk33;  /*merge Error a/b/c dataset with junk33 */
keep _SOURCE_ DF SS;
proc print;
title2 "Do we have <splitsplit3>"; run; /*Yes by Laura 23May2010*/
run; title2 ' ';

data splitsplit3; set splitsplit3 end=last;
title1 "Split-Split pieces: Time x CT and Linear contrasts";
retain div dfE dftime dftimeCT timeCT timeLinCT 0;
if _N_ = 3 then dfE=DF; else dfE=dfE+0;      /*This is Error(c) */
if _N_ = 3 then div=SS/DF; else div=div+0;
if _N_ = 5 then dftime=DF; else dftime=dftime+0;  /*df for timexLinCT*/
if _N_ = 7 then dftimeCT=DF; else dftimeCT=dftimeCT+0; /*df for timexCT */
```

```
if _N_ = 7 then timeCT=SS; else timeCT=timeCT+0; /*timexCT SS */
if _N_ < 8 then SS=0;
else if _N_ = 8 then SS=-SS;
timeLinCT=timeLinCT+SS;  /* timexLinCT SS */
if last then do;
 /*to find F and p-values for timexCT, timexLinCT */
 timeCTMS=timeCT/dftimeCT;
 FtimeCT=timeCTMS/div; ptimeCT=1-probf(FtimeCT,dftimeCT,dfE);
 timeLinCTMS=timeLinCT/dftime;
 FtimeLinCT=timeLinCTMS/div; ptimeLinCT=1-probf(FtimeLinCT,dftime,dfE);
 file print;
 put ///'    (timexCT)SS = ' timeCT;
 put / '     (timexCT)MS = ' timeCTMS;
 put /'     F(timexCT) = ' FtimeCT 'p-value = ' ptimeCT;
 put ///'    (time x LinearCT)SS = ' timeLinCT;
 put / '     (time x LinearCT)MS = ' timeLinCTMS;
 put /'     F(time x LinCT) = ' FtimeLinCT 'p-value = ' ptimeLinCT;
 output;
end;
run;

proc glm data=one outstat=junk34;
title1 "Split-Split pieces: timexCT Quadratic components";
class time CT;
model aw=time|CT/ss3;
contrast "Quadratic CT" CT -1 2 -1;
contrast "QuadraticCT@time1" CT -1 2 -1 time*CT -1 2 -1;
contrast "QuadraticCT@time2" CT -1 2 -1 time*CT 0 0 0 -1 2 -1;
run;

proc print data=junk34;
title2 "Do we have <junk34>"; run; /*Yes by Laura 23May2010*/

/*Find time x LinearCT Contrast*/
data splitsplit4;
set ER junk34;  /*merge Error a/b/c dataset with junk34 */
keep _SOURCE_ DF SS;
proc print;
title2 "Do we have <splitsplit4>"; run; /*Yes by Laura 23May2010*/
run; title2 ' ';

data splitsplit4; set splitsplit4 end=last;
title1 "Split-Split pieces: time x CT Quadratic contrasts";
retain div dfE dftime timeQuadCT 0;
if _N_ = 3 then dfE=DF; else dfE=dfE+0;      /*This is Error(c) */
if _N_ = 3 then div=SS/DF; else div=div+0;
if _N_ = 5 then dftime=DF; else dftime=dftime+0;  /*df for timexQuadCT*/
if _N_ < 8 then SS=0;
else if _N_ = 8 then SS=-SS;
timeQuadCT=timeQuadCT+SS;  /* timexQuadCT SS */
if last then do;
 /*to find F and p-values for timexQuadCT */
 timeQuadCTMS=timeQuadCT/dftime;
 FtimeQuadCT=timeQuadCTMS/div; ptimeQuadCT=1-probf(FtimeQuadCT,dftime,dfE);
 file print;
 put ///'    (time x QuadraticCT)SS = ' timeQuadCT;
```

```
 put / '     (time x QuadraticCT)MS = ' timeQuadCTMS;
 put /'     F(time x QuadraticCT) = ' FtimeQuadCT 'p-value = ' ptimeQuadCT;
 output;
end;
run;


/*CT x RT pieces */
proc glm data=one outstat=junk33;
title1 "Split-Split pieces: RTxCT and Linear components";
class RT CT;
model aw=RT|CT/ss3;
contrast "Linear CT" CT -1 0 1;
contrast "LinearCT@RT1" CT -1 0 1 RT*CT -1 0 1;
contrast "LinearCT@RT2" CT -1 0 1 RT*CT 0 0 0 -1 0 1;
run;

proc print data=junk33;
title2 "Do we have <junk33>"; run; /*Yes Laura 23May2010*/

/*Find RT x LinearCT Contrast*/
data splitsplit3;
set ER junk33;  /*merge Error a/b/c dataset with junk33 */
keep _SOURCE_ DF SS;
proc print;
title2 "Do we have <splitsplit3>"; run; /*Yes Laura 23May2010*/
run; title2 ' ';

data splitsplit3; set splitsplit3 end=last;
title1 "Split-Split pieces: RT x CT and Linear contrasts";
retain div dfE dfRT dfRTCT RTCT RTLinCT 0;
if _N_ = 3 then dfE=DF; else dfE=dfE+0;      /*This is Error(c) */
if _N_ = 3 then div=SS/DF; else div=div+0;
if _N_ = 5 then dfRT=DF; else dfRT=dfRT+0;  /*df for RTxLinCT*/
if _N_ = 7 then dfRTCT=DF; else dfRTCT=dfRTCT+0; /*df for RTxCT */
if _N_ = 7 then RTCT=SS; else RTCT=RTCT+0; /*RTxCT SS */
if _N_ < 8 then SS=0;
else if _N_ = 8 then SS=-SS;
RTLinCT=RTLinCT+SS;  /* RTxLinCT SS */
if last then do;
 /*to find F and p-values for RTxCT, RTxLinCT */
 RTCTMS=RTCT/dfRTCT;
 FRTCT=RTCTMS/div; pRTCT=1-probf(FRTCT,dfRTCT,dfE);
 RTLinCTMS=RTLinCT/dfRT;
 FRTLinCT=RTLinCTMS/div; pRTLinCT=1-probf(FRTLinCT,dfRT,dfE);
 file print;
 put ///'    (RTxCT)SS = ' RTCT;
 put / '     (RTxCT)MS = ' RTCTMS;
 put /'     F(RTxCT) = ' FRTCT 'p-value = ' pRTCT;
 put ///'    (RT x LinearCT)SS = ' RTLinCT;
 put / '     (RT x LinearCT)MS = ' RTLinCTMS;
 put /'     F(RT x LinCT) = ' FRTLinCT 'p-value = ' pRTLinCT;
 output;
end;
run;
```

```
proc glm data=one outstat=junk34;
title1 "Split-Split pieces: RTxCT Quadratic components";
class RT CT;
model aw=RT|CT/ss3;
contrast "Quadratic CT" CT -1 2 -1;
contrast "QuadraticCT@RT1" CT -1 2 -1 RT*CT -1 2 -1;
contrast "Quadratic@RT2" CT -1 2 -1 RT*CT 0 0 0 -1 2 -1;
run;

proc print data=junk34;
title2 "Do we have <junk34>"; run; /*Yes Laura 23May2010*/

/*Find RT x LinearCT Contrast*/
data splitsplit4;
set ER junk34;  /*merge Error a/b/c dataset with junk34 */
keep _SOURCE_ DF SS;
proc print;
title2 "Do we have <splitsplit4>"; run; /*Yes Laura 23May2010*/
run; title2 ' ';

data splitsplit4; set splitsplit4 end=last;
title1 "Split-Split pieces: RT x CT Quadratic contrasts";
retain div dfE dfRT RTQuadCT 0;
if _N_ = 3 then dfE=DF; else dfE=dfE+0;      /*This is Error(c) */
if _N_ = 3 then div=SS/DF; else div=div+0;
if _N_ = 5 then dfRT=DF; else dfRT=dfRT+0;  /*df for RTxQuadCT*/
if _N_ < 8 then SS=0;
else if _N_ = 8 then SS=-SS;
RTQuadCT=RTQuadCT+SS;  /* RTxQuadCT SS */
if last then do;
  /*to find F and p-values for RTxQuadCT */
  RTQuadCTMS=RTQuadCT/dfRT;
  FRTQuadCT=RTQuadCTMS/div; pRTQuadCT=1-probf(FRTQuadCT,dfRT,dfE);
  file print;
  put ///'     (RT x QuadraticCT)SS = ' RTQuadCT;
  put / '      (RT x QuadraticCT)MS = ' RTQuadCTMS;
  put /'      F(RT x QuadraticCT) = ' FRTQuadCT 'p-value = ' pRTQuadCT;
  output;
end;
run;

/*size RT time pieces */
proc glm data=one outstat=junk35;
title1 "Split-Split pieces: size, RT, time and Linear components";
class size RT time;
model aw=size|RT|time/ss3;
run;

proc print data=junk35;
title2 "Do we have <junk35>"; run; /*Yes Laura 23May2010*/

/*Find size x LinearTime Contrast*/
data splitsplit5;
set ER junk35;  /*merge Error a/b/c dataset with junk35 */
keep _SOURCE_ DF SS;
proc print;
```

```
title2 "Do we have <splitsplit5>"; run; /*Yes Laura 23May2010*/
run; title2 ' ';

data splitsplit5; set splitsplit5 end=last;
title1 "Split-Split pieces: size, RT, time and Linear contrasts";
retain div dfE dfS dfSRT dfStime dfSRTtime Size SRT Stime SRTtime 0;
if _N_ = 3 then dfE=DF; else dfE=dfE+0;      /*This is Error(c) */
if _N_ = 3 then div=SS/DF; else div=div+0;
if _N_ = 5 then dfS=DF; else dfS=dfS+0;  /*df for size*/
if _N_ = 5 then Size=SS; else Size=Size+0; /* Size SS */
if _N_ = 7 then dfSRT=DF; else dfSRT=dfSRT+0; /*df for sizexRT */
if _N_ = 7 then SRT=SS; else SRT=SRT+0; /*sizexRT SS */
if _N_ = 9 then dfStime=DF; else dfStime=dfStime+0;  /* size x time df */
if _N_ = 9 then Stime=SS; else Stime=Stime+0; /* sizexTime SS */
if _N_ = 11 then dfSRTtime=DF; else dfSRTtime=dfSRTtime+0;  /* df for sizexRTxtime */
if _N_ = 11 then SRTtime=SS; else SRTtime=SRTtime+0;  /* size x RT x time SS */
if _N_ < 12 then SS=0;
else if _N_ = 12 then SS=-SS;
if last then do;
  /*to find F and p-values  */
  SizeMS=Size/dfS;
  FSize=SizeMS/div; pSize=1-probf(FSize,dfS,dfE);
  SRTMS= SRT/dfSRT;
  FSRT=SRTMS/div; pSRT=1-probf(FSRT,dfSRT,dfE);
  StimeMS=Stime/dfStime;
  FStime=StimeMS/div; pStime=1-probf(FStime,dfStime,dfE);
  SRTtimeMS=SRTtime/dfSRTtime;
  FSRTtime=SRTtimeMS/div; pSRTtime=1-probf(FSRTtime,dfSRTtime,dfE);
  file print;
  put ///'     (Size)SS  = ' Size;
  put / '      (Size)MS = ' SizeMS;
  put /'      F(Size) = ' FSize 'p-value = ' pSize;
  put///'      (SizexRT)SS  =  ' SRT;
  put/ '       (SizexRT)MS  =  ' SRTMS;
  put/ '      F(SizexRT)  =  ' FSRT ' p-value = ' pSRT;
  put///'      (SizexTime)SS = ' Stime;
  put/ '       (SizexTime)MS = ' StimeMS;
  put/ '      F(SizexTime)  =  ' FStime '  p-value = ' pStime;
  put///'       (SizexRTxTime)SS = ' SRTtime;
  put/'       (SizexRTxTime)MS = ' SRTtimeMS;
  put/ '      F(SizexRTxTime) = ' FSRTtime  '    p-value = ' pSRTtime;
  output;
end;
run;

/*size CT pieces */
proc glm data=one outstat=junk37;
title1 "Split-Split pieces: size CT Linear components";
class size CT;
model aw=size|CT/ss3;
contrast "Linear CT" CT -1 0 1;
contrast "LinCT@size1" CT -1 0 1 size*CT -1 0 1;
contrast "LinCT@size2" CT -1 0 1 size*CT 0 0 0 -1 0 1;
run;

proc print data=junk37;
```

```
title2 "Do we have <junk37>"; run; /*Yes Laura 23May2010*/

/*Find size x LinearCT Contrast*/
data splitsplit7;
set ER junk37;  /*merge Error a/b/c dataset with junk37 */
keep _SOURCE_ DF SS;
proc print;
title2 "Do we have <splitsplit7>"; run; /*Yes Laura 23May2010*/
run; title2 ' ';

data splitsplit7; set splitsplit7 end=last;
title1 "Split-Split pieces: size, CT Linear contrasts";
retain div dfE dfS dfSCT SCT SLinCT 0;
if _N_ = 3 then dfE=DF; else dfE=dfE+0;      /*This is Error(c) */
if _N_ = 3 then div=SS/DF; else div=div+0;
if _N_ = 5 then dfS=DF; else dfS=dfS+0;  /*df for SizexLinCT */
if _N_ = 7 then dfSCT=DF; else dfSCT=dfSCT+0; /*df for sizexCT */
if _N_ = 7 then SCT=SS; else SCT=SCT+0; /*sizexCT SS */
if _N_ < 8 then SS=0;
else if _N_ = 8 then SS=-SS;
SLinCT=SLinCT+SS;  /* sizexLinCT SS */
if last then do;
 /*to find F and p-values  */
 SCTMS= SCT/dfSCT;
 FSCT=SCTMS/div; pSCT=1-probf(FSCT,dfSCT,dfE);
 SLinCTMS=SLinCT/dfS;
 FSLinCT=SLinCTMS/div; pSLinCT=1-probf(FSLinCT,dfS,dfE);
 file print;
 put///'     (SizexCT)SS  =  ' SCT;
 put/ '      (SizexCT)MS  =  ' SCTMS;
 put/ '     F(SizexCT)  =  ' FSCT ' p-value = ' pSCT;
 put ///'    (Size x LinearCT)SS = ' SLinCT;
 put / '     (Size x LinearCT)MS = ' SLinCTMS;
 put /'     F(Size x LinearCT) = ' FSLinCT 'p-value = ' pSLinCT;
 output;
end;
run;

proc glm data=one outstat=junk38;
title1 "Split-Split pieces: size CT quadratic components";
class size CT;
model aw=size|CT/ss3;
contrast "Quadratic CT" CT -1 2 -1;
contrast "QuadCT@size1" CT -1 2 -1 size*CT -1 2 -1;
contrast "QuadCT@size2" CT -1 2 -1 size*CT 0 0 0 -1 2 -1;
run;

proc print data=junk38;
title2 "Do we have <junk38>"; run; /*Yes Laura 23May2010*/

/*Find size x Quadratic CT Contrast*/
data splitsplit8;
set ER junk38;  /*merge Error a/b/c dataset with junk38 */
keep _SOURCE_ DF SS;
proc print;
title2 "Do we have <splitsplit8>"; run; /*Yes Laura 23May2010*/
```

```
run; title2 ' ';
data splitsplit8; set splitsplit8 end=last;
title1 "Split-Split pieces: Size CT Quadratic contrasts";
retain div dfE dfS SQuadCT 0;
if _N_ = 3 then dfE=DF; else dfE=dfE+0;      /*This is Error(c) */
if _N_ = 3 then div=SS/DF; else div=div+0;
if _N_ = 5 then dfS=DF; else dfS=dfS+0;  /*df for SizexQuadCT*/
if _N_ < 8 then SS=0;
else if _N_ = 8 then SS=-SS;
SQuadCT=SQuadCT+SS;  /* SizexQuadCT SS */
if last then do;
  /*to find F and p-values for SizexQuadCT */
  SQuadCTMS=SQuadCT/dfS;
  FSQuadCT=SQuadCTMS/div; pSQuadCT=1-probf(FSQuadCT,dfS,dfE);
  file print;
  put ///'     (Size x Quad CT)SS = ' SQuadCT;
  put / '      (Size x Quad CT)MS = ' SQuadCTMS;
  put /'      F(Size x Quad CT) = ' FSQuadCT 'p-value = ' pSQuadCT;
  output;
end;
run;



/*abrade CT pieces */
proc glm data=one outstat=junk39;
title1 "Split-Split pieces: abrade CT Linear components";
class abrade CT;
model aw=abrade|CT/ss3;
contrast "Linear CT" CT -1 0 1;
contrast "LinCT@abrade1" CT -1 0 1 abrade*CT -1 0 1;
contrast "LinCT@abrade2" CT -1 0 1 abrade*CT 0 0 0 -1 0 1;
run;

proc print data=junk39;
title2 "Do we have <junk39>"; run; /*Yes Laura 23May2010*/

/*Find size x LinearCT Contrast*/
data splitsplit9;
set ER junk39;  /*merge Error a/b/c dataset with junk39 */
keep _SOURCE_ DF SS;
proc print;
title2 "Do we have <splitsplit9>"; run; /*Yes Laura 23May2010*/
run; title2 ' ';

data splitsplit9; set splitsplit9 end=last;
title1 "Split-Split pieces: Abrade, CT Linear contrasts";
retain div dfE dfAb dfAbCT Ab AbCT AbLinCT 0;
if _N_ = 3 then dfE=DF; else dfE=dfE+0;      /*This is Error(c) */
if _N_ = 3 then div=SS/DF; else div=div+0;
if _N_ = 5 then dfAb=DF; else dfAb=dfAb+0;  /*df for AbradexLinCT, and Abrade */
if _N_ = 5 then Ab=SS; else Ab=Ab+0;  /*Abrade SS*/
if _N_ = 7 then dfAbCT=DF; else dfAbCT=dfAbCT+0; /*df for AbradexCT */
if _N_ = 7 then AbCT=SS; else AbCT=AbCT+0; /*AbradexCT SS */
if _N_ < 8 then SS=0;
else if _N_ = 8 then SS=-SS;
```

```
AbLinCT=AbLinCT+SS;  /* abradexLinCT SS */
if last then do;
 /*to find F and p-values  */
 AbMS=Ab/dfAb;
 FAb=AbMS/div; pAb=1-probf(FAb,dfAb,dfE);
 AbCTMS= AbCT/dfAbCT;
 FAbCT=AbCTMS/div; pAbCT=1-probf(FAbCT,dfAbCT,dfE);
 AbLinCTMS=AbLinCT/dfAb;
 FAbLinCT=AbLinCTMS/div; pAbLinCT=1-probf(FAbLinCT,dfAb,dfE);
 file print;
 put///'     (Abrade)SS = ' Ab;
 put/ '      (Abrade)MS = ' AbMS;
 put/ '     F(Abrade) = ' FAb '   p-value = ' pAb;
 put///'     (AbradexCT)SS  =  ' AbCT;
 put/ '      (AbradexCT)MS  =  ' AbCTMS;
 put/ '     F(AbradexCT)  =  ' FAbCT ' p-value = ' pAbCT;
 put ///'    (Abrade x LinearCT)SS = ' AbLinCT;
 put / '     (Abrade x LinearCT)MS = ' AbLinCTMS;
 put /'     F(Abrade x LinearCT) = ' FAbLinCT 'p-value = ' pAbLinCT;
 output;
end;
run;

proc glm data=one outstat=junk310;
title1 "Split-Split pieces: Abrade CT quadratic components";
class abrade CT;
model aw=abrade|CT/ss3;
contrast "Quadratic CT" CT -1 2 -1;
contrast "QuadCT@abrade1" CT -1 2 -1 abrade*CT -1 2 -1;
contrast "QuadCT@abrade2" CT -1 2 -1 abrade*CT 0 0 0 -1 2 -1;
run;

proc print data=junk310;
title2 "Do we have <junk310>"; run; /*Yes Laura 23May2010*/

/*Find abrade x Quadratic CT Contrast*/
data splitsplit10;
set ER junk310;  /*merge Error a/b/c dataset with junk310 */
keep _SOURCE_ DF SS;
proc print;
title2 "Do we have <splitsplit10>"; run; /*Yes Laura 23May2010*/
run; title2 ' ';
data splitsplit10; set splitsplit10 end=last;
title1 "Split-Split pieces: abrade CT Quadratic contrasts";
retain div dfE dfAb AbQuadCT 0;
if _N_ = 3 then dfE=DF; else dfE=dfE+0;      /*This is Error(c) */
if _N_ = 3 then div=SS/DF; else div=div+0;
if _N_ = 5 then dfAb=DF; else dfAb=dfAb+0;  /*df for abradexQuadCT*/
if _N_ < 8 then SS=0;
else if _N_ = 8 then SS=-SS;
AbQuadCT=AbQuadCT+SS;  /* abradexQuadCT SS */
if last then do;
 /*to find F and p-values for abradexQuadCT */
 AbQuadCTMS=AbQuadCT/dfAb;
 FAbQuadCT=AbQuadCTMS/div; pAbQuadCT=1-probf(FAbQuadCT,dfAb,dfE);
 file print;
```

```
  put ///'     (abrade x Quad CT)SS = ' AbQuadCT;
  put / '      (abrade x Quad CT)MS = ' AbQuadCTMS;
  put /'      F(abrade x Quad CT) = ' FAbQuadCT 'p-value = ' pAbQuadCT;
  output;
end;
run;


/*abrade time pieces */
proc glm data=one outstat=junk311;
title1 "Split-Split pieces: abrade time Linear components";
class abrade time;
model aw=abrade|time/ss3;
run;

proc print data=junk311;
title2 "Do we have <junk311>"; run; /*Yes*/

/*Find abrade x Time */
data splitsplit11;
set ER junk311;  /*merge Error a/b/c dataset with junk311 */
keep _SOURCE_ DF SS;
proc print;
title2 "Do we have <splitsplit11>"; run; /*Yes*/
run; title2 ' ';

data splitsplit11; set splitsplit11 end=last;
title1 "Split-Split pieces: Abrade, time";
retain div dfE dfAb dfAbT AbT 0;
if _N_ = 3 then dfE=DF; else dfE=dfE+0;       /*This is Error(c) */
if _N_ = 3 then div=SS/DF; else div=div+0;
if _N_ = 5 then dfAb=DF; else dfAb=dfAb+0;  /*df for Abrade */
if _N_ = 7 then dfAbT=DF; else dfAbT=dfAbT+0; /*df for AbradexT */
if _N_ = 7 then AbT=SS; else AbT=AbT+0; /*AbradexT SS */
if _N_ < 8 then SS=0;
else if _N_ = 8 then SS=-SS;
if last then do;
  /*to find F and p-values  */
  AbTMS= AbT/dfAbT;
  FAbT=AbTMS/div; pAbT=1-probf(FAbT,dfAbT,dfE);
  file print;
  put///'      (AbradexTime)SS  =  ' AbT;
  put/ '       (AbradexTime)MS  =  ' AbTMS;
  put/ '      F(AbradexTime)  =  ' FAbT ' p-value = ' pAbT;
  output;
end;
run;

/*The rest of the story... pieces */
proc glm data=one outstat=junk313;
title1 "Split-Split pieces: not previously covered";
class CT RT time size abrade;
model aw=CT*RT*time size*RT size*CT*time size*RT*time size*CT*RT size*CT*RT*time
   abrade*RT abrade*RT*time abrade*CT*time abrade*CT*RT  abrade*CT*RT*time
   abrade*size abrade*size*time abrade*size*RT abrade*size*RT*time
   abrade*size*CT abrade*size*CT*time abrade*size*CT*RT
```

```
  abrade*size*CT*RT*time/ss3;

run;

proc print data=junk313;
title2 "Do we have <junk313>"; run; /*Yes*/

/*Find rest of pieces*/
data splitsplit13;
set junk313 ER;  /*merge Error a/b/c dataset with junk313 */
keep _SOURCE_ DF SS; output;
proc print;
title2 "Do we have <splitsplit13>"; run; /*Yes*/
run; title2 ' ';

proc iml;
use splitsplit13;
read all var {DF SS} into P;
nr=nrow(P);
FM=J(nr,5,0);
FM[1:nr,1:2]=P[1:nr,1:2];
do r = 1 to nr;
   FM[r,3]=FM[r,2]/FM[r,1];
end;
MSEc=FM[nr,3]; dfE=FM[nr,1];
/*print P FM MSEc; */
do r = 1 to nr;
   FM[r,4]=FM[r,3]/MSEc;
          FM[r,5]=1-probf(FM[r,4],FM[r,1],dfE);
end;
/*print MSEc dfE FM; */
varnames={DF SS MS F p};
create outFP from FM (|colname=varnames|);
append from FM;
run;

data yes;
merge splitsplit13 outFP;
proc print data=yes;
title2 "The rest of the F and p values"; run;
quit;
```

OUTPUT FOR WATER ACTIVITY PRE-FROZEN

Batch Vacuum-belt Drying Analysis 22 May 2010 1

The GLM Procedure

Class Level Information

Class	Levels	Values
rep	6	1 2 3 4 5 6

abrade	2	1 2
size	2	1 2
CT	3	1 2 3
RT	2	1 2
time	2	1 2

Number of Observations Read	288
Number of Observations Used	288

Dependent Variable: aw

Source	DF	Sum of Squares	Mean Square	F Value
Model	287	14.38648872	0.05012714	.
Error	0	0.00000000	.	
Corrected Total	287	14.38648872		

Source	Pr > F
Model	.
Error	
Corrected Total	

R-Square	Coeff Var	Root MSE	aw Mean
1.000000	.	.	0.389365

Source	DF	Type III SS	Mean Square	F Value
time	1	0.95830475	0.95830475	.
RT	1	0.07248528	0.07248528	.
RT*time	1	0.00146250	0.00146250	.
CT	2	4.38489300	2.19244650	.
CT*time	2	0.44412186	0.22206093	.
CT*RT	2	0.44749308	0.22374654	.

CT*RT*time	2	0.16848544	0.08424272	.
size	1	0.01685142	0.01685142	.
size*time	1	0.04674153	0.04674153	.

Source	Pr > F
time	.
RT	.
RT*time	.
CT	.
CT*time	.
CT*RT	.
CT*RT*time	.
size	.
size*time	.

Source	DF	Type III SS	Mean Square	F Value
size*RT	1	0.03031953	0.03031953	.
size*RT*time	1	0.02492028	0.02492028	.
size*CT	2	0.20884103	0.10442051	.
size*CT*time	2	0.04718125	0.02359062	.
size*CT*RT	2	0.03973558	0.01986779	.
size*CT*RT*time	2	0.06441825	0.03220912	.
abrade	1	0.02241903	0.02241903	.
abrade*time	1	0.00477753	0.00477753	.
abrade*RT	1	0.00833125	0.00833125	.
abrade*RT*time	1	0.05464267	0.05464267	.
abrade*CT	2	0.13721458	0.06860729	.
abrade*CT*time	2	0.23750808	0.11875404	.
abrade*CT*RT	2	0.00559419	0.00279710	.
abrade*CT*RT*time	2	0.14651436	0.07325718	.
abrade*size	1	0.00960267	0.00960267	.
abrade*size*time	1	0.09291642	0.09291642	.
abrade*size*RT	1	0.00255017	0.00255017	.
abrade*size*RT*time	1	0.03899028	0.03899028	.
abrade*size*CT	2	0.03996736	0.01998368	.
abrade*size*CT*time	2	0.03273744	0.01636872	.
abrade*size*CT*RT	2	0.05858678	0.02929339	.
abra*size*CT*RT*time	2	0.00554925	0.00277463	.
rep	5	0.82817078	0.16563416	.
rep*time	5	0.06916831	0.01383366	.
rep*RT	5	0.04371661	0.00874332	.
rep*RT*time	5	0.25352623	0.05070525	.
rep*CT	10	0.28592613	0.02859261	.
rep*CT*time	10	0.07496201	0.00749620	.

rep*CT*RT 10 0.21327846 0.02132785 .
rep*CT*RT*time 10 0.24766501 0.02476650 .
rep*size 5 0.17648581 0.03529716 .
rep*size*time 5 0.10808403 0.02161681 .
rep*size*RT 5 0.03757203 0.00751441 .
rep*size*RT*time 5 0.06038378 0.01207676 .
rep*size*CT 10 0.18147393 0.01814739 .
rep*size*CT*time 10 0.37760963 0.03776096 .
rep*size*CT*RT 10 0.27290529 0.02729053 .
rep*size*CT*RT*time 10 0.23379738 0.02337974 .
rep*abrade 5 0.14473986 0.02894797 .
rep*abrade*time 5 0.06194453 0.01238891 .
rep*abrade*RT 5 0.10462131 0.02092426 .
rep*abrade*RT*time 5 0.10726589 0.02145318 .
rep*abrade*CT 10 0.14578596 0.01457860 .
rep*abrade*CT*time 10 0.36513404 0.03651340 .
rep*abrade*CT*RT 10 0.21981743 0.02198174 .
rep*abrad*CT*RT*time 10 0.43549901 0.04354990 .

Source DF Type III SS Mean Square F Value

rep*abrade*size 5 0.08028056 0.01605611 .
rep*abrade*size*time 5 0.19596864 0.03919373 .
rep*abrade*size*RT 5 0.13326156 0.02665231 .
rep*abr*size*RT*time 5 0.23277545 0.04655509 .
rep*abrade*size*CT 10 0.09716235 0.00971623 .
rep*abr*size*CT*time 10 0.51501068 0.05150107 .
rep*abrad*size*CT*RT 10 0.03548218 0.00354822 .
re*abr*siz*CT*RT*tim 10 0.19285696 0.01928570 .

Source Pr > F

rep*abrade*size .
rep*abrade*size*time .
rep*abrade*size*RT .
rep*abr*size*RT*time .
rep*abrade*size*CT .
rep*abr*size*CT*time .
rep*abrad*size*CT*RT .
re*abr*siz*CT*RT*tim .

RT qual, Time qualitative; SOURCE, DF & SS data only....contrasts 7
21:55 Sunday, May 22, 2005

Obs _SOURCE_ DF SS

1	ERROR	0	0.00000
2	time	1	0.95830
3	RT	1	0.07249
4	RT*time	1	0.00146
5	CT	2	4.38489
6	CT*time	2	0.44412
7	CT*RT	2	0.44749
8	CT*RT*time	2	0.16849
9	size	1	0.01685
10	size*time	1	0.04674
11	size*RT	1	0.03032
12	size*RT*time	1	0.02492
13	size*CT	2	0.20884
14	size*CT*time	2	0.04718
15	size*CT*RT	2	0.03974
16	size*CT*RT*time	2	0.06442
17	abrade	1	0.02242
18	abrade*time	1	0.00478
19	abrade*RT	1	0.00833
20	abrade*RT*time	1	0.05464
21	abrade*CT	2	0.13721
22	abrade*CT*time	2	0.23751
23	abrade*CT*RT	2	0.00559
24	abrade*CT*RT*time	2	0.14651
25	abrade*size	1	0.00960
26	abrade*size*time	1	0.09292
27	abrade*size*RT	1	0.00255
28	abrade*size*RT*time	1	0.03899
29	abrade*size*CT	2	0.03997
30	abrade*size*CT*time	2	0.03274
31	abrade*size*CT*RT	2	0.05859
32	abra*size*CT*RT*time	2	0.00555
33	rep	5	0.82817
34	rep*time	5	0.06917
35	rep*RT	5	0.04372
36	rep*RT*time	5	0.25353
37	rep*CT	10	0.28593
38	rep*CT*time	10	0.07496
39	rep*CT*RT	10	0.21328
40	rep*CT*RT*time	10	0.24767
41	rep*size	5	0.17649
42	rep*size*time	5	0.10808
43	rep*size*RT	5	0.03757
44	rep*size*RT*time	5	0.06038
45	rep*size*CT	10	0.18147
46	rep*size*CT*time	10	0.37761

47	rep*size*CT*RT	10	0.27291
48	rep*size*CT*RT*time	10	0.23380
49	rep*abrade	5	0.14474
50	rep*abrade*time	5	0.06194

RT qual, Time qualitative; SOURCE, DF & SS data only....contrasts 8

Obs	_SOURCE_	DF	SS
51	rep*abrade*RT	5	0.10462
52	rep*abrade*RT*time	5	0.10727
53	rep*abrade*CT	10	0.14579
54	rep*abrade*CT*time	10	0.36513
55	rep*abrade*CT*RT	10	0.21982
56	rep*abrad*CT*RT*time	10	0.43550
57	rep*abrade*size	5	0.08028
58	rep*abrade*size*time	5	0.19597
59	rep*abrade*size*RT	5	0.13326
60	rep*abr*size*RT*time	5	0.23278
61	rep*abrade*size*CT	10	0.09716
62	rep*abr*size*CT*time	10	0.51501
63	rep*abrad*size*CT*RT	10	0.03548
64	re*abr*siz*CT*RT*tim	10	0.19286

RT qual, Time qualitative; SOURCE, DF & SS data only....contrasts 9

ER		EC	
5	0.0691683	10	0.2859261
10	0.2972428	10	0.074962
220	5.3377499	10	0.2132785
		10	0.247665
		5	0.1764858
		5	0.108084
		5	0.037572
		5	0.0603838
		10	0.1814739
		10	0.3776096
		10	0.2729053
		10	0.2337974
		5	0.1447399
		5	0.0619445
		5	0.1046213
		5	0.1072659
		10	0.145786
		10	0.365134

10 0.2198174
10 0.435499
5 0.0802806
5 0.1959686
5 0.1332616
5 0.2327754
10 0.0971623
10 0.5150107
10 0.0354822
10 0.192857

Is this two2 10

Obs	_SOURCE_	DF	SS
1	ERROR	0	0.00000
2	time	1	0.95830
3	RT	1	0.07249
4	RT*time	1	0.00146
5	CT	2	4.38489
6	CT*time	2	0.44412
7	CT*RT	2	0.44749
8	CT*RT*time	2	0.16849
9	size	1	0.01685
10	size*time	1	0.04674
11	size*RT	1	0.03032
12	size*RT*time	1	0.02492
13	size*CT	2	0.20884
14	size*CT*time	2	0.04718
15	size*CT*RT	2	0.03974
16	size*CT*RT*time	2	0.06442
17	abrade	1	0.02242
18	abrade*time	1	0.00478
19	abrade*RT	1	0.00833
20	abrade*RT*time	1	0.05464
21	abrade*CT	2	0.13721
22	abrade*CT*time	2	0.23751
23	abrade*CT*RT	2	0.00559
24	abrade*CT*RT*time	2	0.14651
25	abrade*size	1	0.00960
26	abrade*size*time	1	0.09292
27	abrade*size*RT	1	0.00255
28	abrade*size*RT*time	1	0.03899
29	abrade*size*CT	2	0.03997
30	abrade*size*CT*time	2	0.03274
31	abrade*size*CT*RT	2	0.05859

Obs	_SOURCE_	DF	SS
32	abra*size*CT*RT*time	2	0.00555
33	rep	5	0.82817
34	rep*time	5	0.06917
35	rep*RT	5	0.04372
36	rep*RT*time	5	0.25353
37	rep*CT	10	0.28593
38	rep*CT*time	10	0.07496
39	rep*CT*RT	10	0.21328
40	rep*CT*RT*time	10	0.24767
41	rep*size	5	0.17649
42	rep*size*time	5	0.10808
43	rep*size*RT	5	0.03757
44	rep*size*RT*time	5	0.06038
45	rep*size*CT	10	0.18147
46	rep*size*CT*time	10	0.37761
47	rep*size*CT*RT	10	0.27291
48	rep*size*CT*RT*time	10	0.23380
49	rep*abrade	5	0.14474
50	rep*abrade*time	5	0.06194

Is this two2 11

Obs	_SOURCE_	DF	SS
51	rep*abrade*RT	5	0.10462
52	rep*abrade*RT*time	5	0.10727
53	rep*abrade*CT	10	0.14579
54	rep*abrade*CT*time	10	0.36513
55	rep*abrade*CT*RT	10	0.21982
56	rep*abrad*CT*RT*time	10	0.43550
57	rep*abrade*size	5	0.08028
58	rep*abrade*size*time	5	0.19597
59	rep*abrade*size*RT	5	0.13326
60	rep*abr*size*RT*time	5	0.23278
61	rep*abrade*size*CT	10	0.09716
62	rep*abr*size*CT*time	10	0.51501
63	rep*abrad*size*CT*RT	10	0.03548
64	re*abr*siz*CT*RT*tim	10	0.19286
65	ERRORA	5	0.06917
66	ERRORB	10	0.29724
67	ERRORC	220	5.33775

Whole Plot pieces: Time and reps 12

Class Level Information

Class	Levels	Values
time	2	1 2
rep	6	1 2 3 4 5 6

Number of Observations Read	288
Number of Observations Used	288

Whole Plot pieces: Time and reps 13

Source	DF	Sum of Squares	Mean Square	F Value
Model	11	1.85564384	0.16869489	3.72
Error	276	12.53084487	0.04540161	
Corrected Total	287	14.38648872		

Source	Pr > F
Model	<.0001
Error	
Corrected Total	

R-Square	Coeff Var	Root MSE	aw Mean
0.128985	54.72417	0.213077	0.389365

Source	DF	Type III SS	Mean Square	F Value
time	1	0.95830475	0.95830475	21.11
rep	5	0.82817078	0.16563416	3.65
time*rep	5	0.06916831	0.01383366	0.30

Source	Pr > F
time	<.0001
rep	0.0033
time*rep	0.9099

Whole Plot pieces: Time and reps 14

Do we have <junk1>

Obs	_NAME_	_SOURCE_	_TYPE_	DF	SS	F	PROB
1	aw	ERROR	ERROR	276	12.5308	.	.
2	aw	time	SS3	1	0.9583	21.1073	0.00001
3	aw	rep	SS3	5	0.8282	3.6482	0.00326
4	aw	time*rep	SS3	5	0.0692	0.3047	0.90987

Whole Plot pieces: Time and reps 15

Do we have <wholeplot>

Obs	DF	SS	_SOURCE_
1	5	0.0692	ERRORA
2	10	0.2972	ERRORB
3	220	5.3377	ERRORC
4	276	12.5308	ERROR
5	1	0.9583	time
6	5	0.8282	rep
7	5	0.0692	time*r

Whole Plot pieces: Time, Rep 16

(time)SS = 0.9583047535

(time)MS = 0.9583047535

F(time) = 69.273397524 p-value = 0.0004092212

(rep)SS = 0.8281707813

(rep)MS = 0.1656341563

F(rep) = 11.973269159 p-value = 0.0082325021

Split plot pieces: RT, RTxTime 17

The GLM Procedure

Class Level Information

Class	Levels	Values
RT	2	1 2

time 2 1 2

Number of Observations Read 288
Number of Observations Used 288

Split plot pieces: RT, RTxTime 18

The GLM Procedure

Dependent Variable: aw

Source	DF	Sum of Squares	Mean Square	F Value
Model	3	1.03225254	0.34408418	7.32
Error	284	13.35423618	0.04702196	
Corrected Total	287	14.38648872		

Source	Pr > F
Model	<.0001
Error	
Corrected Total	

R-Square	Coeff Var	Root MSE	aw Mean
0.071752	55.69214	0.216845	0.389365

Source	DF	Type III SS	Mean Square	F Value
RT	1	0.07248528	0.07248528	1.54
time	1	0.95830475	0.95830475	20.38
RT*time	1	0.00146250	0.00146250	0.03

Source	Pr > F
RT	0.2154
time	<.0001

RT*time 0.8601

Do we have <junk2> 19

Obs	_NAME_	_SOURCE_	_TYPE_	DF	SS	F	PROB
1	aw	ERROR	ERROR	284	13.3542	.	.
2	aw	RT	SS3	1	0.0725	1.5415	0.21542
3	aw	time	SS3	1	0.9583	20.3799	0.00001
4	aw	RT*time	SS3	1	0.0015	0.0311	0.86014

Do we have <junk2> 20

Do we have <split1>

Obs	DF	SS	_SOURCE_
1	5	0.0692	ERRORA
2	10	0.2972	ERRORB
3	220	5.3377	ERRORC
4	284	13.3542	ERROR
5	1	0.0725	RT
6	1	0.9583	time
7	1	0.0015	RT*tim

Split Plot pieces: RT, RT*Time and Linear contrasts 21

(RT)SS = 0.0724852813

(RT)MS = 0.0724852813

F(RT) = 2.4385879634 p-value = 0.1494455793

(RTxTime)SS = 0.0014625035

(RTxTime)MS = 0.0014625035

F(RTxTime) = 0.0492023112 p-value = 0.8289214203

Split-Split pieces: CT, and CT contrasts 22

The GLM Procedure

Class Level Information

Class	Levels	Values

CT 3 1 2 3

Number of Observations Read 288
Number of Observations Used 288

Split-Split pieces: CT, and CT contrasts 23

The GLM Procedure

Dependent Variable: aw

Source	DF	Sum of Squares	Mean Square	F Value
Model	2	4.38489300	2.19244650	62.47
Error	285	10.00159572	0.03509332	
Corrected Total	287	14.38648872		

Source	Pr > F
Model	<.0001
Error	
Corrected Total	

R-Square	Coeff Var	Root MSE	aw Mean
0.304792	48.11226	0.187332	0.389365

Source	DF	Type III SS	Mean Square	F Value
CT	2	4.38489300	2.19244650	62.47

Source	Pr > F
CT	<.0001

Contrast	DF	Contrast SS	Mean Square	F Value
Linear CT	1	4.16305200	4.16305200	118.63
Quad CT	1	0.22184100	0.22184100	6.32

Contrast	Pr > F

Linear CT <.0001
Quad CT 0.0125

Split-Split pieces: CT, and CT contrasts 24
Do we have <junk3>

Obs	_NAME_	_SOURCE_	_TYPE_	DF	SS	F	PROB
1	aw	ERROR	ERROR	285	10.0016	.	.
2	aw	CT	SS3	2	4.3849	62.475	0.000000
3	aw	Linear CT	CONTRAST	1	4.1631	118.628	0.000000
4	aw	Quad CT	CONTRAST	1	0.2218	6.321	0.012480

Split-Split pieces: CT, and CT contrasts 25
Do we have <splitsplit>

Obs	DF	SS	_SOURCE_
1	5	0.0692	ERRORA
2	10	0.2972	ERRORB
3	220	5.3377	ERRORC
4	285	10.0016	ERROR
5	2	4.3849	CT
6	1	4.1631	Linear
7	1	0.2218	Quad C

Split-Split pieces: CT, and CT contrasts 26

(CT)SS = 4.384893

(CT)MS = 2.1924465

F(CT) = 90.363587426 p-value = 0

(Linear CT)SS = 4.163052

(Linear CT)MS = 4.163052

F(LinCT) = 171.58380529 p-value = 0

(Quad CT)SS = 0.221841

(Quad CT)MS = 0.221841

F(Quad CT) = 9.1433695638 p-value = 0.0027926709

Split-Split pieces: TimexCT and Linear components 27

The GLM Procedure

Class Level Information

Class	Levels	Values
time	2	1 2
CT	3	1 2 3

Number of Observations Read 288
Number of Observations Used 288

Split-Split pieces: TimexCT and Linear components 28

The GLM Procedure

Dependent Variable: aw

Source	DF	Sum of Squares	Mean Square	F Value
Model	5	5.78731961	1.15746392	37.96
Error	282	8.59916910	0.03049351	
Corrected Total	287	14.38648872		

Source	Pr > F
Model	<.0001
Error	
Corrected Total	

R-Square	Coeff Var	Root MSE	aw Mean
0.402275	44.84843	0.174624	0.389365

Source	DF	Type III SS	Mean Square	F Value
time	1	0.95830475	0.95830475	31.43

CT 2 4.38489300 2.19244650 71.90
time*CT 2 0.44412186 0.22206093 7.28

Source	Pr > F
time	<.0001
CT	<.0001
time*CT	0.0008

Contrast	DF	Contrast SS	Mean Square	F Value
Linear CT	1	4.16305200	4.16305200	136.52
LinearCT@Time1	1	3.62898151	3.62898151	119.01
LinearCT@Time2	1	0.96140051	0.96140051	31.53

Contrast	Pr > F
Linear CT	<.0001
LinearCT@Time1	<.0001
LinearCT@Time2	<.0001

Split-Split pieces: TimexCT and Linear components 29
Do we have <junk33>

Obs	_NAME_	_SOURCE_	_TYPE_	DF	SS	F	PROB
1	aw	ERROR	ERROR	282	8.59917	.	.
2	aw	time	SS3	1	0.95830	31.427	.000000049
3	aw	CT	SS3	2	4.38489	71.899	5.8543E-26
4	aw	time*CT	SS3	2	0.44412	7.282	.000824761
5	aw	Linear CT	CONTRAST	1	4.16305	136.523	5.4871E-26
6	aw	LinearCT@Time1	CONTRAST	1	3.62898	119.008	2.3832E-23
7	aw	LinearCT@Time2	CONTRAST	1	0.96140	31.528	.000000047

Split-Split pieces: TimexCT and Linear components 30
Do we have <splitsplit3>

Obs	DF	SS	_SOURCE_
1	5	0.06917	ERRORA
2	10	0.29724	ERRORB
3	220	5.33775	ERRORC
4	282	8.59917	ERROR
5	1	0.95830	time
6	2	4.38489	CT
7	2	0.44412	time*C

8	1	4.16305	Linear
9	1	3.62898	Linear
10	1	0.96140	Linear

Split-Split pieces: Time x CT and Linear contrasts 31

(timexCT)SS = 0.4441218611

(timexCT)MS = 0.2220609306

F(timexCT) = 9.1524341927 p-value = 0.0001520107

(time x LinearCT)SS = 0.4273300208

(time x LinearCT)MS = 0.4273300208

F(time x LinCT) = 17.612778099 p-value = 0.000039297

Split-Split pieces: timexCT Quadratic components 32

The GLM Procedure

Class Level Information

Class	Levels	Values
time	2	1 2
CT	3	1 2 3

Number of Observations Read	288
Number of Observations Used	288

Split-Split pieces: timexCT Quadratic components 33

The GLM Procedure

Dependent Variable: aw

Source	DF	Sum of Squares	Mean Square	F Value
Model	5	5.78731961	1.15746392	37.96
Error	282	8.59916910	0.03049351	

Corrected Total 287 14.38648872

Source	Pr > F
Model	<.0001
Error	
Corrected Total	

R-Square	Coeff Var	Root MSE	aw Mean
0.402275	44.84843	0.174624	0.389365

Source	DF	Type III SS	Mean Square	F Value
time	1	0.95830475	0.95830475	31.43
CT	2	4.38489300	2.19244650	71.90
time*CT	2	0.44412186	0.22206093	7.28

Source	Pr > F
time	<.0001
CT	<.0001
time*CT	0.0008

Contrast	DF	Contrast SS	Mean Square	F Value
Quadratic CT	1	0.22184100	0.22184100	7.28
QuadraticCT@time1	1	0.18035017	0.18035017	5.91
QuadraticCT@time2	1	0.05828267	0.05828267	1.91

Contrast	Pr > F
Quadratic CT	0.0074
QuadraticCT@time1	0.0156
QuadraticCT@time2	0.1679

Split-Split pieces: timexCT Quadratic components 34
Do we have <junk34>

Obs	_NAME_	_SOURCE_	_TYPE_	DF	SS	F	PROB
1	aw	ERROR	ERROR	282	8.59917	.	.
2	aw	time	SS3	1	0.95830	31.4265	0.00000
3	aw	CT	SS3	2	4.38489	71.8988	0.00000

4	aw	time*CT	SS3	2	0.44412	7.2822	0.00082
5	aw	Quadratic CT	CONTRAST	1	0.22184	7.2750	0.00741
6	aw	QuadraticCT@time1	CONTRAST	1	0.18035	5.9144	0.01564
7	aw	QuadraticCT@time2	CONTRAST	1	0.05828	1.9113	0.16791

Split-Split pieces: timexCT Quadratic components 35

Do we have <splitsplit4>

Obs	DF	SS	_SOURCE_
1	5	0.06917	ERRORA
2	10	0.29724	ERRORB
3	220	5.33775	ERRORC
4	282	8.59917	ERROR
5	1	0.95830	time
6	2	4.38489	CT
7	2	0.44412	time*C
8	1	0.22184	Quadra
9	1	0.18035	Quadra
10	1	0.05828	Quadra

Split-Split pieces: time x CT Quadratic contrasts 36

21:55 Sunday, May 22, 2005

(time x QuadraticCT)SS = 0.0167918403

(time x QuadraticCT)MS = 0.0167918403

F(time x QuadraticCT) = 0.6920902868 p-value = 0.40635639

Split-Split pieces: RTxCT and Linear components 37

The GLM Procedure

Class Level Information

Class	Levels	Values
RT	2	1 2
CT	3	1 2 3

Number of Observations Read 288
Number of Observations Used 288

Split-Split pieces: RTxCT and Linear components 38

The GLM Procedure

Dependent Variable: aw

Source	DF	Sum of Squares	Mean Square	F Value
Model	5	4.90487136	0.98097427	29.18
Error	282	9.48161735	0.03362276	
Corrected Total	287	14.38648872		

Source	Pr > F
Model	<.0001
Error	
Corrected Total	

R-Square	Coeff Var	Root MSE	aw Mean
0.340936	47.09342	0.183365	0.389365

Source	DF	Type III SS	Mean Square	F Value
RT	1	0.07248528	0.07248528	2.16
CT	2	4.38489300	2.19244650	65.21
RT*CT	2	0.44749308	0.22374654	6.65

Source	Pr > F
RT	0.1431
CT	<.0001
RT*CT	0.0015

Contrast	DF	Contrast SS	Mean Square	F Value
Linear CT	1	4.16305200	4.16305200	123.82
LinearCT@RT1	1	1.86790501	1.86790501	55.55
LinearCT@RT2	1	2.30671001	2.30671001	68.61

Contrast	Pr > F

Linear CT <.0001
LinearCT@RT1 <.0001
LinearCT@RT2 <.0001

Split-Split pieces: RTxCT and Linear components 39
Do we have <junk33>
21:55 Sunday, May 22, 2005

Obs	_NAME_	_SOURCE_	_TYPE_	DF	SS	F	PROB
1	aw	ERROR	ERROR	282	9.48162	.	.
2	aw	RT	SS3	1	0.07249	2.156	0.14314
3	aw	CT	SS3	2	4.38489	65.207	0.00000
4	aw	RT*CT	SS3	2	0.44749	6.655	0.00150
5	aw	Linear CT	CONTRAST	1	4.16305	123.816	0.00000
6	aw	LinearCT@RT1	CONTRAST	1	1.86791	55.555	0.00000
7	aw	LinearCT@RT2	CONTRAST	1	2.30671	68.606	0.00000

Split-Split pieces: RTxCT and Linear components 40
Do we have <splitsplit3>

Obs	DF	SS	_SOURCE_
1	5	0.06917	ERRORA
2	10	0.29724	ERRORB
3	220	5.33775	ERRORC
4	282	9.48162	ERROR
5	1	0.07249	RT
6	2	4.38489	CT
7	2	0.44749	RT*CT
8	1	4.16305	Linear
9	1	1.86791	Linear
10	1	2.30671	Linear

Split-Split pieces: RT x CT and Linear contrasts 41

(RTxCT)SS = 0.4474930833

(RTxCT)MS = 0.2237465417

F(RTxCT) = 9.2219081192 p-value = 0.0001425699

(RT x LinearCT)SS = 0.0115630208

(RT x LinearCT)MS = 0.0115630208

F(RT x LinCT) = 0.4765799503 p-value = 0.4907032068

Split-Split pieces: RTxCT Quadratic components 42

The GLM Procedure

Class Level Information

Class	Levels	Values
RT	2	1 2
CT	3	1 2 3

Number of Observations Read 288
Number of Observations Used 288

Split-Split pieces: RTxCT Quadratic components 43

The GLM Procedure

Dependent Variable: aw

Source	DF	Sum of Squares	Mean Square	F Value
Model	5	4.90487136	0.98097427	29.18
Error	282	9.48161735	0.03362276	
Corrected Total	287	14.38648872		

Source	Pr > F
Model	<.0001
Error	
Corrected Total	

R-Square	Coeff Var	Root MSE	aw Mean
0.340936	47.09342	0.183365	0.389365

Source	DF	Type III SS	Mean Square	F Value

RT	1	0.07248528	0.07248528	2.16
CT	2	4.38489300	2.19244650	65.21
RT*CT	2	0.44749308	0.22374654	6.65

Source	Pr > F
RT	0.1431
CT	<.0001
RT*CT	0.0015

Contrast	DF	Contrast SS	Mean Square	F Value
Quadratic CT	1	0.22184100	0.22184100	6.60
QuadraticCT@RT1	1	0.01790778	0.01790778	0.53
Quadratic@RT2	1	0.63986328	0.63986328	19.03

Contrast	Pr > F
Quadratic CT	0.0107
QuadraticCT@RT1	0.4661
Quadratic@RT2	<.0001

Split-Split pieces: RTxCT Quadratic components 44
Do we have <junk34>

Obs	_NAME_	_SOURCE_	_TYPE_	DF	SS	F	PROB
1	aw	ERROR	ERROR	282	9.48162	.	.
2	aw	RT	SS3	1	0.07249	2.1558	0.14314
3	aw	CT	SS3	2	4.38489	65.2072	0.00000
4	aw	RT*CT	SS3	2	0.44749	6.6546	0.00150
5	aw	Quadratic CT	CONTRAST	1	0.22184	6.5979	0.01072
6	aw	QuadraticCT@RT1	CONTRAST	1	0.01791	0.5326	0.46612
7	aw	Quadratic@RT2	CONTRAST	1	0.63986	19.0307	0.00002

Split-Split pieces: RTxCT Quadratic components 45
Do we have <splitsplit4>

Obs	DF	SS	_SOURCE_
1	5	0.06917	ERRORA
2	10	0.29724	ERRORB
3	220	5.33775	ERRORC
4	282	9.48162	ERROR
5	1	0.07249	RT

6	2	4.38489	CT
7	2	0.44749	RT*CT
8	1	0.22184	Quadra
9	1	0.01791	Quadra
10	1	0.63986	Quadra

Split-Split pieces: RT x CT Quadratic contrasts 46

(RT x QuadraticCT)SS = 0.4359300625

(RT x QuadraticCT)MS = 0.4359300625

F(RT x QuadraticCT) = 17.967236288 p-value = 0.0000330774

Split-Split pieces: size, RT, time and Linear components 47

The GLM Procedure

Class Level Information

Class	Levels	Values
size	2	1 2
RT	2	1 2
time	2	1 2

Number of Observations Read 288
Number of Observations Used 288

Split-Split pieces: size, RT, time and Linear components 48

The GLM Procedure

Dependent Variable: aw

Source	DF	Sum of Squares	Mean Square	F Value
Model	7	1.15108530	0.16444076	3.48
Error	280	13.23540342	0.04726930	
Corrected Total	287	14.38648872		

Source	Pr > F
Model	0.0014
Error	
Corrected Total	

R-Square	Coeff Var	Root MSE	aw Mean
0.080012	55.83842	0.217415	0.389365

Source	DF	Type III SS	Mean Square	F Value
size	1	0.01685142	0.01685142	0.36
RT	1	0.07248528	0.07248528	1.53
size*RT	1	0.03031953	0.03031953	0.64
time	1	0.95830475	0.95830475	20.27
size*time	1	0.04674153	0.04674153	0.99
RT*time	1	0.00146250	0.00146250	0.03
size*RT*time	1	0.02492028	0.02492028	0.53

Source	Pr > F
size	0.5509
RT	0.2166
size*RT	0.4239
time	<.0001
size*time	0.3209
RT*time	0.8605
size*RT*time	0.4684

Split-Split pieces: size, RT, time and Linear components 49

Do we have <junk35>

Obs	_NAME_	_SOURCE_	_TYPE_	DF	SS	F	PROB
1	aw	ERROR	ERROR	280	13.2354	.	.
2	aw	size	SS3	1	0.0169	0.3565	0.55094
3	aw	RT	SS3	1	0.0725	1.5335	0.21663
4	aw	size*RT	SS3	1	0.0303	0.6414	0.42388
5	aw	time	SS3	1	0.9583	20.2733	0.00001
6	aw	size*time	SS3	1	0.0467	0.9888	0.32089
7	aw	RT*time	SS3	1	0.0015	0.0309	0.86050
8	aw	size*RT*time	SS3	1	0.0249	0.5272	0.46839

Split-Split pieces: size, RT, time and Linear components 50
Do we have <splitsplit5>

Obs	DF	SS	_SOURCE_
1	5	0.0692	ERRORA
2	10	0.2972	ERRORB
3	220	5.3377	ERRORC
4	280	13.2354	ERROR
5	1	0.0169	size
6	1	0.0725	RT
7	1	0.0303	size*R
8	1	0.9583	time
9	1	0.0467	size*t
10	1	0.0015	RT*tim
11	1	0.0249	size*R

Split-Split pieces: size, RT, time and Linear contrasts 51

(Size)SS = 0.0168514201

(Size)MS = 0.0168514201

F(Size) = 0.6945459225 p-value = 0.4055263178

(SizexRT)SS = 0.0303195313

(SizexRT)MS = 0.0303195313

F(SizexRT) = 1.2496458239 p-value = 0.2648393579

(SizexTime)SS = 0.0467415312

(SizexTime)MS = 0.0467415312

F(SizexTime) = 1.9264928223 p-value = 0.1665466767

(SizexRTxTime)SS = 0.0249202812

(SizexRTxTime)MS = 0.0249202812

F(SizexRTxTime) = 1.027111044 p-value = 0.3119514639

Split-Split pieces: size CT Linear components 52
The GLM Procedure

Class Level Information

Class	Levels	Values
size	2	1 2
CT	3	1 2 3

Number of Observations Read 288
Number of Observations Used 288

Split-Split pieces: size CT Linear components 53
21:55 Sunday, May 22, 2005

The GLM Procedure

Dependent Variable: aw

Source	DF	Sum of Squares	Mean Square	F Value
Model	5	4.61058545	0.92211709	26.60
Error	282	9.77590327	0.03466632	
Corrected Total	287	14.38648872		

Source	Pr > F
Model	<.0001
Error	
Corrected Total	

R-Square	Coeff Var	Root MSE	aw Mean
0.320480	47.81867	0.186189	0.389365

Source	DF	Type III SS	Mean Square	F Value
size	1	0.01685142	0.01685142	0.49
CT	2	4.38489300	2.19244650	63.24
size*CT	2	0.20884103	0.10442051	3.01

Source	Pr > F
size	0.4862
CT	<.0001
size*CT	0.0508

Contrast	DF	Contrast SS	Mean Square	F Value
Linear CT	1	4.16305200	4.16305200	120.09
LinCT@size1	1	2.39622801	2.39622801	69.12
LinCT@size2	1	1.78896901	1.78896901	51.61

Contrast	Pr > F
Linear CT	<.0001
LinCT@size1	<.0001
LinCT@size2	<.0001

Split-Split pieces: size CT Linear components 54
Do we have <junk37>

Obs	_NAME_	_SOURCE_	_TYPE_	DF	SS	F	PROB
1	aw	ERROR	ERROR	282	9.77590	.	.
2	aw	size	SS3	1	0.01685	0.486	0.48625
3	aw	CT	SS3	2	4.38489	63.244	0.00000
4	aw	size*CT	SS3	2	0.20884	3.012	0.05077
5	aw	Linear CT	CONTRAST	1	4.16305	120.089	0.00000
6	aw	LinCT@size1	CONTRAST	1	2.39623	69.123	0.00000
7	aw	LinCT@size2	CONTRAST	1	1.78897	51.605	0.00000

Split-Split pieces: size CT Linear components 55
Do we have <splitsplit7>

Obs	DF	SS	_SOURCE_
1	5	0.06917	ERRORA
2	10	0.29724	ERRORB
3	220	5.33775	ERRORC
4	282	9.77590	ERROR
5	1	0.01685	size
6	2	4.38489	CT
7	2	0.20884	size*C
8	1	4.16305	Linear
9	1	2.39623	LinCT@
10	1	1.78897	LinCT@

Split-Split pieces: size, CT Linear contrasts 56

(SizexCT)SS = 0.2088410278

(SizexCT)MS = 0.1044205139

F(SizexCT) = 4.3037822067 p-value = 0.0146733492

(Size x LinearCT)SS = 0.0221450208

(Size x LinearCT)MS = 0.0221450208

F(Size x LinearCT) = 0.9127262746 p-value = 0.3404406815

Split-Split pieces: size CT quadratic components 57

The GLM Procedure

Class Level Information

Class	Levels	Values
size	2	1 2
CT	3	1 2 3

Number of Observations Read 288
Number of Observations Used 288

Split-Split pieces: size CT quadratic components 58

The GLM Procedure

Dependent Variable: aw

Source	DF	Sum of Squares	Mean Square	F Value
Model	5	4.61058545	0.92211709	26.60
Error	282	9.77590327	0.03466632	
Corrected Total	287	14.38648872		

Source Pr > F

Model <.0001

Error

Corrected Total

R-Square	Coeff Var	Root MSE	aw Mean
0.320480	47.81867	0.186189	0.389365

Source	DF	Type III SS	Mean Square	F Value
size	1	0.01685142	0.01685142	0.49
CT	2	4.38489300	2.19244650	63.24
size*CT	2	0.20884103	0.10442051	3.01

Source	Pr > F
size	0.4862
CT	<.0001
size*CT	0.0508

Contrast	DF	Contrast SS	Mean Square	F Value
Quadratic CT	1	0.22184100	0.22184100	6.40
QuadCT@size1	1	0.00075725	0.00075725	0.02
QuadCT@size2	1	0.40777975	0.40777975	11.76

Contrast	Pr > F
Quadratic CT	0.0120
QuadCT@size1	0.8826
QuadCT@size2	0.0007

Split-Split pieces: size CT quadratic components 59

Do we have <junk38>

21:55 Sunday, May 22, 2005

Obs	_NAME_	_SOURCE_	_TYPE_	DF	SS	F	PROB
1	aw	ERROR	ERROR	282	9.77590	.	.
2	aw	size	SS3	1	0.01685	0.4861	0.48625
3	aw	CT	SS3	2	4.38489	63.2443	0.00000
4	aw	size*CT	SS3	2	0.20884	3.0122	0.05077
5	aw	Quadratic CT	CONTRAST	1	0.22184	6.3993	0.01196

6	aw	QuadCT@size1	CONTRAST	1	0.00076	0.0218	0.88261
7	aw	QuadCT@size2	CONTRAST	1	0.40778	11.7630	0.00069

Split-Split pieces: size CT quadratic components 60

Do we have <splitsplit8>

Obs	DF	SS	_SOURCE_
1	5	0.06917	ERRORA
2	10	0.29724	ERRORB
3	220	5.33775	ERRORC
4	282	9.77590	ERROR
5	1	0.01685	size
6	2	4.38489	CT
7	2	0.20884	size*C
8	1	0.22184	Quadra
9	1	0.00076	QuadCT
10	1	0.40778	QuadCT

Split-Split pieces: Size CT Quadratic contrasts 61

(Size x Quad CT)SS = 0.1866960069

(Size x Quad CT)MS = 0.1866960069

F(Size x Quad CT) = 7.6948381389 p-value = 0.0060136561

Split-Split pieces: abrade CT Linear components 62

The GLM Procedure

Class Level Information

Class	Levels	Values
abrade	2	1 2
CT	3	1 2 3

Number of Observations Read 288
Number of Observations Used 288

Split-Split pieces: abrade CT Linear components 63

The GLM Procedure

Dependent Variable: aw

Source	DF	Sum of Squares	Mean Square	F Value
Model	5	4.54452661	0.90890532	26.04
Error	282	9.84196210	0.03490057	
Corrected Total	287	14.38648872		

Source	Pr > F
Model	<.0001
Error	
Corrected Total	

R-Square	Coeff Var	Root MSE	aw Mean
0.315889	47.97996	0.186817	0.389365

Source	DF	Type III SS	Mean Square	F Value
abrade	1	0.02241903	0.02241903	0.64
CT	2	4.38489300	2.19244650	62.82
abrade*CT	2	0.13721458	0.06860729	1.97

Source	Pr > F
abrade	0.4235
CT	<.0001
abrade*CT	0.1420

Contrast	DF	Contrast SS	Mean Square	F Value
Linear CT	1	4.16305200	4.16305200	119.28
LinCT@abrade1	1	2.69206017	2.69206017	77.14
LinCT@abrade2	1	1.54940017	1.54940017	44.39

Contrast	Pr > F
Linear CT	<.0001
LinCT@abrade1	<.0001
LinCT@abrade2	<.0001

Split-Split pieces: abrade CT Linear components 64
Do we have <junk39>

Obs	_NAME_	_SOURCE_	_TYPE_	DF	SS	F	PROB
1	aw	ERROR	ERROR	282	9.84196	.	.
2	aw	abrade	SS3	1	0.02242	0.642	0.42353
3	aw	CT	SS3	2	4.38489	62.820	0.00000
4	aw	abrade*CT	SS3	2	0.13721	1.966	0.14196
5	aw	Linear CT	CONTRAST	1	4.16305	119.283	0.00000
6	aw	LinCT@abrade1	CONTRAST	1	2.69206	77.135	0.00000
7	aw	LinCT@abrade2	CONTRAST	1	1.54940	44.395	0.00000

Split-Split pieces: abrade CT Linear components 65
Do we have <splitsplit9>

Obs	DF	SS	_SOURCE_
1	5	0.06917	ERRORA
2	10	0.29724	ERRORB
3	220	5.33775	ERRORC
4	282	9.84196	ERROR
5	1	0.02242	abrade
6	2	4.38489	CT
7	2	0.13721	abrade
8	1	4.16305	Linear
9	1	2.69206	LinCT@
10	1	1.54940	LinCT@

Split-Split pieces: Abrade, CT Linear contrasts 66

(Abrade)SS = 0.0224190313

(Abrade)MS = 0.0224190313

F(Abrade) = 0.924019852 p-value = 0.3374770055

(AbradexCT)SS = 0.1372145833

(AbradexCT)MS = 0.0686072917

F(AbradexCT) = 2.8277091362 p-value = 0.0613000229

(Abrade x LinearCT)SS = 0.0784083333

(Abrade x LinearCT)MS = 0.0784083333

F(Abrade x LinearCT) = 3.2316675842 p-value = 0.0735983096

Split-Split pieces: Abrade CT quadratic components 67

The GLM Procedure

Class Level Information

Class	Levels	Values
abrade	2	1 2
CT	3	1 2 3

Number of Observations Read 288
Number of Observations Used 288

Split-Split pieces: Abrade CT quadratic components 68

The GLM Procedure

Dependent Variable: aw

Source	DF	Sum of Squares	Mean Square	F Value
Model	5	4.54452661	0.90890532	26.04
Error	282	9.84196210	0.03490057	
Corrected Total	287	14.38648872		

Source	Pr > F
Model	<.0001
Error	
Corrected Total	

R-Square	Coeff Var	Root MSE	aw Mean
0.315889	47.97996	0.186817	0.389365

Source	DF	Type III SS	Mean Square	F Value
abrade	1	0.02241903	0.02241903	0.64
CT	2	4.38489300	2.19244650	62.82
abrade*CT	2	0.13721458	0.06860729	1.97

Source	Pr > F
abrade	0.4235
CT	<.0001
abrade*CT	0.1420

Contrast	DF	Contrast SS	Mean Square	F Value
Quadratic CT	1	0.22184100	0.22184100	6.36
QuadCT@abrade1	1	0.25454112	0.25454112	7.29
QuadCT@abrade2	1	0.02610613	0.02610613	0.75

Contrast	Pr > F
Quadratic CT	0.0122
QuadCT@abrade1	0.0073
QuadCT@abrade2	0.3878

Split-Split pieces: Abrade CT quadratic components 69
Do we have <junk310>

Obs	_NAME_	_SOURCE_	_TYPE_	DF	SS	F	PROB
1	aw	ERROR	ERROR	282	9.84196	.	.
2	aw	abrade	SS3	1	0.02242	0.6424	0.42353
3	aw	CT	SS3	2	4.38489	62.8198	0.00000
4	aw	abrade*CT	SS3	2	0.13721	1.9658	0.14196
5	aw	Quadratic CT	CONTRAST	1	0.22184	6.3564	0.01225
6	aw	QuadCT@abrade1	CONTRAST	1	0.25454	7.2933	0.00734
7	aw	QuadCT@abrade2	CONTRAST	1	0.02611	0.7480	0.38784

Split-Split pieces: Abrade CT quadratic components 70
Do we have <splitsplit10>

Obs	DF	SS	_SOURCE_
1	5	0.06917	ERRORA

2	10	0.29724	ERRORB
3	220	5.33775	ERRORC
4	282	9.84196	ERROR
5	1	0.02242	abrade
6	2	4.38489	CT
7	2	0.13721	abrade
8	1	0.22184	Quadra
9	1	0.25454	QuadCT
10	1	0.02611	QuadCT

Split-Split pieces: abrade CT Quadratic contrasts 71

(abrade x Quad CT)SS = 0.05880625

(abrade x Quad CT)MS = 0.05880625

F(abrade x Quad CT) = 2.4237506881 p-value = 0.1209458446

Split-Split pieces: abrade time Linear components 72

The GLM Procedure

Class Level Information

Class	Levels	Values
abrade	2	1 2
time	2	1 2

Number of Observations Read 288
Number of Observations Used 288

Split-Split pieces: abrade time Linear components 73

The GLM Procedure

Dependent Variable: aw

Source	DF	Sum of Squares	Mean Square	F Value
Model	3	0.98550132	0.32850044	6.96
Error	284	13.40098740	0.04718658	

Corrected Total 287 14.38648872

Source	Pr > F
Model	0.0002
Error	
Corrected Total	

R-Square	Coeff Var	Root MSE	aw Mean
0.068502	55.78954	0.217225	0.389365

Source	DF	Type III SS	Mean Square	F Value
abrade	1	0.02241903	0.02241903	0.48
time	1	0.95830475	0.95830475	20.31
abrade*time	1	0.00477753	0.00477753	0.10

Source	Pr > F
abrade	0.4912
time	<.0001
abrade*time	0.7506

Split-Split pieces: abrade time Linear components 74
Do we have <junk311>

Obs	_NAME_	_SOURCE_	_TYPE_	DF	SS	F	PROB
1	aw	ERROR	ERROR	284	13.4010	.	.
2	aw	abrade	SS3	1	0.0224	0.4751	0.49121
3	aw	time	SS3	1	0.9583	20.3088	0.00001
4	aw	abrade*time	SS3	1	0.0048	0.1012	0.75057

Split-Split pieces: abrade time Linear components 75
Do we have <splitsplit11>

Obs	DF	SS	_SOURCE_
1	5	0.0692	ERRORA
2	10	0.2972	ERRORB
3	220	5.3377	ERRORC
4	284	13.4010	ERROR
5	1	0.0224	abrade

6	1	0.9583	time
7	1	0.0048	abrade

Split-Split pieces: Abrade, time 76

(AbradexTime)SS = 0.0047775312

(AbradexTime)MS = 0.0047775312

F(AbradexTime) = 0.1969101015 p-value = 0.6576626849

Split-Split pieces: not previously covered 77

The GLM Procedure

Class Level Information

Class	Levels	Values
CT	3	1 2 3
RT	2	1 2
time	2	1 2
size	2	1 2
abrade	2	1 2

Number of Observations Read 288
Number of Observations Used 288

Split-Split pieces: not previously covered 78

The GLM Procedure

Dependent Variable: aw

Source	DF	Sum of Squares	Mean Square	F Value
Model	47	7.85415689	0.16710972	6.14
Error	240	6.53233183	0.02721805	
Corrected Total	287	14.38648872		

Source	Pr > F
Model	<.0001
Error	
Corrected Total	

R-Square	Coeff Var	Root MSE	aw Mean
0.545940	42.37133	0.164979	0.389365

Source	DF	Type III SS	Mean Square	F Value
CT*RT*time	2	0.16848544	0.08424272	3.10
RT*size	1	0.03031953	0.03031953	1.11
CT*time*size	2	0.04718125	0.02359062	0.87
RT*time*size	1	0.02492028	0.02492028	0.92
CT*RT*size	2	0.03973558	0.01986779	0.73
CT*RT*time*size	2	0.06441825	0.03220913	1.18
RT*abrade	1	0.00833125	0.00833125	0.31
RT*time*abrade	1	0.05464267	0.05464267	2.01
CT*time*abrade	2	0.23750808	0.11875404	4.36

Source	Pr > F
CT*RT*time	0.0471
RT*size	0.2923
CT*time*size	0.4216
RT*time*size	0.3396
CT*RT*size	0.4830
CT*RT*time*size	0.3080
RT*abrade	0.5806
RT*time*abrade	0.1578
CT*time*abrade	0.0138

Split-Split pieces: not previously covered 79

The GLM Procedure

Dependent Variable: aw

Source	DF	Type III SS	Mean Square	F Value
CT*RT*abrade	2	0.00559419	0.00279710	0.10

CT*RT*time*abrade 2 0.14651436 0.07325718 2.69
size*abrade 1 0.00960267 0.00960267 0.35
time*size*abrade 1 0.09291642 0.09291642 3.41
RT*size*abrade 1 0.00255017 0.00255017 0.09
RT*time*size*abrade 1 0.03899028 0.03899028 1.43
CT*size*abrade 2 0.03996736 0.01998368 0.73
CT*time*size*abrade 2 0.03273744 0.01636872 0.60
CT*RT*size*abrade 2 0.05858678 0.02929339 1.08
CT*RT*time*size*abra 2 0.00554925 0.00277462 0.10

Source Pr > F

CT*RT*abrade 0.9024
CT*RT*time*abrade 0.0698
size*abrade 0.5531
time*size*abrade 0.0659
RT*size*abrade 0.7598
RT*time*size*abrade 0.2325
CT*size*abrade 0.4810
CT*time*size*abrade 0.5489
CT*RT*size*abrade 0.3425
CT*RT*time*size*abra 0.9031

Split-Split pieces: not previously covered 80
Do we have <junk313>

Obs	_NAME_	_SOURCE_	_TYPE_	DF	SS	F	PROB
1	aw	ERROR	ERROR	240	6.53233	.	.
2	aw	CT*RT*time	SS3	2	0.16849	3.09511	0.04708
3	aw	RT*size	SS3	1	0.03032	1.11395	0.29229
4	aw	CT*time*size	SS3	2	0.04718	0.86673	0.42164
5	aw	RT*time*size	SS3	1	0.02492	0.91558	0.33960
6	aw	CT*RT*size	SS3	2	0.03974	0.72995	0.48300
7	aw	CT*RT*time*size	SS3	2	0.06442	1.18337	0.30802
8	aw	RT*abrade	SS3	1	0.00833	0.30609	0.58060
9	aw	RT*time*abrade	SS3	1	0.05464	2.00759	0.15781
10	aw	CT*time*abrade	SS3	2	0.23751	4.36306	0.01377
11	aw	CT*RT*abrade	SS3	2	0.00559	0.10277	0.90238
12	aw	CT*RT*time*abrade	SS3	2	0.14651	2.69149	0.06983
13	aw	size*abrade	SS3	1	0.00960	0.35281	0.55309
14	aw	time*size*abrade	SS3	1	0.09292	3.41378	0.06588
15	aw	RT*size*abrade	SS3	1	0.00255	0.09369	0.75980
16	aw	RT*time*size*abrade	SS3	1	0.03899	1.43252	0.23254
17	aw	CT*size*abrade	SS3	2	0.03997	0.73421	0.48096
18	aw	CT*time*size*abrade	SS3	2	0.03274	0.60139	0.54887

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 19  aw  CT*RT*size*abrade    SS3      2 0.05859 1.07625 0.34251
 20  aw  CT*RT*time*size*abra SS3      2 0.00555 0.10194 0.90312

          Split-Split pieces: not previously covered          81
               Do we have <splitsplit13>

         Obs   _SOURCE_              DF      SS

          1    ERROR                240    6.53233
          2    CT*RT*time             2    0.16849
          3    RT*size                1    0.03032
          4    CT*time*size           2    0.04718
          5    RT*time*size           1    0.02492
          6    CT*RT*size             2    0.03974
          7    CT*RT*time*size        2    0.06442
          8    RT*abrade              1    0.00833
          9    RT*time*abrade         1    0.05464
         10    CT*time*abrade         2    0.23751
         11    CT*RT*abrade           2    0.00559
         12    CT*RT*time*abrade      2    0.14651
         13    size*abrade            1    0.00960
         14    time*size*abrade       1    0.09292
         15    RT*size*abrade         1    0.00255
         16    RT*time*size*abrade    1    0.03899
         17    CT*size*abrade         2    0.03997
         18    CT*time*size*abrade    2    0.03274
         19    CT*RT*size*abrade      2    0.05859
         20    CT*RT*time*size*abra   2    0.00555
         21    ERRORA                 5    0.06917
         22    ERRORB                10    0.29724
         23    ERRORC               220    5.33775

          Split-Split pieces: not previously covered          82
              The rest of the F and p values

Obs   _SOURCE_              DF      SS       MS       F       P

 1    ERROR                240    6.53233   0.02722   1.12182   0.19297
 2    CT*RT*time             2    0.16849   0.08424   3.47214   0.03276
 3    RT*size                1    0.03032   0.03032   1.24965   0.26484
 4    CT*time*size           2    0.04718   0.02359   0.97231   0.37983
 5    RT*time*size           1    0.02492   0.02492   1.02711   0.31195
 6    CT*RT*size             2    0.03974   0.01987   0.81887   0.44227
 7    CT*RT*time*size        2    0.06442   0.03221   1.32753   0.26725
 8    RT*abrade              1    0.00833   0.00833   0.34338   0.55849
 9    RT*time*abrade         1    0.05464   0.05464   2.25215   0.13486
```

10	**CT*time*abrade**	**2**	**0.23751**	**0.11875**	**4.89455**	**0.00832**
11	**CT*RT*abrade**	**2**	**0.00559**	**0.00280**	**0.11528**	**0.89117**
12	**CT*RT*time*abrade**	**2**	**0.14651**	**0.07326**	**3.01936**	**0.05086**
13	**size*abrade**	**1**	**0.00960**	**0.00960**	**0.39578**	**0.52993**
14	**time*size*abrade**	**1**	**0.09292**	**0.09292**	**3.82963**	**0.05162**
15	**RT*size*abrade**	**1**	**0.00255**	**0.00255**	**0.10511**	**0.74609**
16	**RT*time*size*abrade**	**1**	**0.03899**	**0.03899**	**1.60702**	**0.20625**
17	**CT*size*abrade**	**2**	**0.03997**	**0.01998**	**0.82364**	**0.44018**
18	**CT*time*size*abrade**	**2**	**0.03274**	**0.01637**	**0.67465**	**0.51038**
19	**CT*RT*size*abrade**	**2**	**0.05859**	**0.02929**	**1.20735**	**0.30096**
20	**CT*RT*time*size*abra**	**2**	**0.00555**	**0.00277**	**0.11436**	**0.89199**
21	ERRORA	5	0.06917	0.01383	0.57017	0.72283
22	ERRORB	10	0.29724	0.02972	1.22511	0.27599
23	ERRORC	220	5.33775	0.02426	1.00000	0.5000

MOISTURE CONTENT PROGRAM

```
/* Split-Split Plot Design... */

dm 'output; clear; log; clear';
options ls=72 ps=55 pageno=1 formdlim=' ';
title 'Split-Split Plot Statistical Analysis of Frozen Blueberry Final MC';
title1 'Batch Vacuum-belt Drying Analysis 23 May 2010';
data one;
do time=1 to 2;
      do RT=1 to 2;
            do CT=1 to 3;
                  do size=1 to 2;
                        do abrade=1 to 2;
                              do rep=1 to 6;

input mc@@;
output;
end;
end;
end;
end;
end;
end;


cards;
0.307 0.633 0.282 0.158 0.242 0.024 0.331 0.227 0.278 0.121 0.092 0.062
0.113 0.173 0.199 0.217 0.090 0.296 0.384 0.173 0.208 0.153 0.203 0.080
0.270 0.397 0.184 0.145 0.088 0.062 0.033 0.094 0.016 0.323 0.242 0.472
0.042 0.100 0.121 0.073 0.075 0.052 0.128 0.099 0.145 0.018 0.174 0.022
0.033 0.013 0.015 0.001 0.001 0.002 0.014 0.021 0.030 0.009 0.016 0.006
0.025 0.020 0.017 0.053 0.007 0.005 0.054 0.073 0.140 0.016 0.011 0.004
0.078 0.390 0.269 0.278 0.199 0.157 0.515 0.566 0.557 0.200 0.087 0.188
0.405 0.260 0.004 0.287 0.033 0.205 0.380 0.562 0.567 0.166 0.134 0.281
0.057 0.029 0.033 0.014 0.004 0.130 0.058 0.024 0.015 0.021 0.030 0.018
0.022 0.023 0.019 0.075 0.045 0.070 0.016 0.218 0.083 0.013 0.016 0.013
```

```
0.013 0.007 0.014 0.017 0.016 0.020 0.009 0.016 0.006 0.008 0.000 0.015
0.121 0.006 0.011 0.017 0.014 0.021 0.007 0.013 0.003 0.145 0.212 0.240
0.210 0.088 0.066 0.127 0.108 0.044 0.182 0.069 0.127 0.068 0.014 0.253
0.089 0.103 0.142 0.127 0.175 0.030 0.047 0.021 0.234 0.057 0.093 0.185
0.016 0.075 0.041 0.111 0.001 0.130 0.260 0.350 0.268 0.000 0.000 0.000
0.009 0.026 0.014 0.007 0.011 0.012 0.019 0.025 0.013 0.022 0.107 0.148
0.012 0.007 0.013 0.004 0.006 0.003 0.030 0.007 0.017 0.009 0.060 0.063
0.008 0.006 0.009 0.010 0.011 0.099 0.114 0.018 0.022 0.007 0.005 0.008
0.192 0.219 0.238 0.074 0.012 0.015 0.044 0.707 0.125 0.015 0.022 0.034
0.672 0.137 0.669 0.227 0.064 0.101 0.040 0.024 0.032 0.027 0.072 0.031
0.018 0.026 0.014 0.009 0.008 0.041 0.226 0.144 0.149 0.011 0.009 0.042
0.000 0.000 0.000 0.027 0.009 0.015 0.015 0.000 0.036 0.015 0.035 0.020
0.012 0.008 0.008 0.003 0.009 0.015 0.013 0.023 0.029 0.027 0.013 0.013
0.011 0.011 0.031 0.007 0.008 0.010 0.020 0.053 0.170 0.007 0.007 0.010
;
/*proc print; run; /*Yes by Laura 23May 2010*/
proc glm data=one outstat=junk1;
class rep abrade size CT RT time;
model mc=time|RT|CT|size|abrade|rep /ss3;
means time RT CT size abrade;
run;

data two;
set junk1;
keep _SOURCE_ DF SS;
output;
proc print data=two;
title 'RT qual, Time qualitative; SOURCE, DF & SS data only....contrasts';
run;


/*To find Error a/b/c SS and DFs */
data two2; set two;
proc iml;
use two2;
read all var {DF SS} into P;
ER=J(3,2,0);
/*Error terms, col1=df, col2=SS; row1-2-3=Error(a)-(b)-(c) */
ER[1,1]=P[34,1]; ER[1,2]=P[34,2];
ER[2,1]=P[35,1]+P[36,1]; ER[2,2]=P[35,2]+P[36,2];
EC=J(28,2,0); /*To collect all 28 rep*effects for Error(c) */
EC[1:28,1:2]=P[37:64,1:2];
ER[3,1]=EC[+,1]; ER[3,2]=EC[+,2]; /*sum over rows of EC */
print ER EC; /*OK by Laura 23 May 2010*/
varnames={DF SS};
create outER from ER (|colname=varnames|);
append from ER;
run;

data ER; set outER;     /*This ER dataset has ErrorSSa/b/c */
if _N_ = 1 then _SOURCE_ = 'ERRORA';
if _N_ = 2 then _SOURCE_ = 'ERRORB';
if _N_ = 3 then _SOURCE_ = 'ERRORC';
output; run;
data two2;
set two ER;
proc print data=two2;
```

```
title "Is this two2"; run; /*OK by Laura 23 May 2010*/


/*WHOLE PLOTS part */
proc glm data=one outstat=junk1;
title1 "Whole Plot pieces: Time and reps";
class time rep;
model mc=time|rep /ss3;
run;

proc print data=junk1;
title2 "Do we have <junk1>"; run; /*Yes Laura 23 May 2010*/

/*Find Time, Rep */
data wholeplot;
set ER junk1;  /*merge Error a/b/c dataset with junk1 */
keep _SOURCE_ DF SS;
proc print;
title2 "Do we have <wholeplot>"; run; /*Yes Laura 23May2010*/
run;
title2 ' ';
data wholeplot; set wholeplot end=last;
title1 "Whole Plot pieces: Time, Rep";
retain div dfE dfT dfrep time rep Trep 0;
if _N_ = 1 then dfE=DF; else dfE=dfE+0;     /*This is Error(a) */
if _N_ = 1 then div=SS/DF; else div=div+0;
if _N_ = 5 then dfT=DF; else dfT=dfT+0; /*df for time */
if _N_ = 6 then dfrep=DF; else dfrep=dfrep+0; /*df for rep */
if _N_ = 5 then time=SS; else time=time+0; /* Time SS */
if _N_ = 6 then rep=SS; else rep=rep+0; /*rep SS */
if _N_ < 8 then SS=0;
if last then do;
  /*to find F and p-values for Time, Rep */
  timeMS=time/dfT;    /* time MS */
  Ftime=timeMS/div; ptime=1-probf(Ftime,dfT,dfE); /* Time F-, p- values*/
  repMS=rep/dfrep;
  Frep=repMS/div; prep=1-probf(Frep,dfrep,dfE);
  file print;
  put ///'     (time)SS = ' time;
  put / '      (time)MS = ' timeMS;
  put /'      F(time) = ' Ftime 'p-value = ' ptime;
  put ///'     (rep)SS = ' rep;
  put / '      (rep)MS = ' repMS;
  put /'      F(rep) = ' Frep 'p-value = ' prep;
  output;
end;
run;

/*SPLIT-PLOT part */
proc glm data=one outstat=junk2;
title1 "Split plot pieces: RT, RTxTime";
class RT time;
model mc=RT|time/ss3;
run;

proc print data=junk2;
title "Do we have <junk2>"; run; /*Yes by Laura 23May2010*/
```

```
/*Find RT, RT x Time */
data split1;
set ER junk2;  /*merge Error a/b/c dataset with junk2 */
keep _SOURCE_ DF SS;
proc print;
title2 "Do we have <split1>"; run; /*Yes Laura 23May2010*/
run;
title2 ' ';
data split1; set split1 end=last;
title1 "Split Plot pieces: RT, RT*Time and Linear contrasts";
retain div dfE dfRT dfRTtime RT RTtime RTLinT 0;
if _N_ = 2 then dfE=DF; else dfE=dfE+0;     /*This is Error(b) */
if _N_ = 2 then div=SS/DF; else div=div+0;
if _N_ = 5 then dfRT=DF; else dfRT=dfRT+0;
if _N_ = 7 then dfRTtime=DF; else dfRTtime=dfRTtime+0; /*df for RTxTime */
if _N_ = 5 then RT=SS; else RT=RT+0; /* RT SS */
if _N_ = 7 then RTtime=SS; else RTtime=RTtime+0; /*RTxTime SS */
if _N_ < 8 then SS=0;
if last then do;
  /*to find F and p-values for RT, RTxTime */
  RTMS=RT/dfRT;    /* RT MS */
  FRT=RTMS/div; pRT=1-probf(FRT,dfRT,dfE); /* RT F-, p- values*/
  RTtimeMS=RTtime/dfRTtime;
  FRTtime=RTtimeMS/div; pRTtime=1-probf(FRTtime,dfRTtime,dfE);
  file print;
  put ///'     (RT)SS = ' RT;
  put / '      (RT)MS = ' RTMS;
  put /'      F(RT) = ' FRT 'p-value = ' pRT;
  put ///'     (RTxTime)SS = ' RTtime;
  put / '      (RTxTime)MS = ' RTtimeMS;
  put /'      F(RTxTime) = ' FRTtime 'p-value = ' pRTtime;
  output;
end;
run;

/* SPLIT-SPLIT-PLOT part (Will do this in pieces, to try to avoid mistakes in
using the outstat datasets-pull together results at end */
proc glm data=one outstat=junk3;
title1 "Split-Split pieces: CT, and CT contrasts";
class CT;
model mc=CT/ss3;
contrast "Linear CT" CT -1 0 1;
contrast "Quad CT" CT -1 2 -1;
run;
proc print data=junk3;
title2 "Do we have <junk3>"; run; /*Yes by Laura 22May2010*/

data splitsplit;
set ER junk3; /*merge Error a/b/c dataset with junk3 */
keep _SOURCE_ DF SS;
proc print;
title2 "Do we have <splitsplit>"; run; /*Yes by Laura 22May2010*/
run; title2 ' ';
data splitsplit; set splitsplit end=last;
title1 "Split-Split pieces: CT, and CT contrasts";
retain div dfE dfCT CT LinCT QuadCT 0;
```

```
if _N_ = 3 then dfE=DF; else dfE=dfE+0;     /*This is Error(c) */
if _N_ = 3 then div=SS/DF; else div=div+0;
if _N_ = 5 then dfCT=DF; else dfCT=dfCT+0;   /*CT df */
if _N_ = 5 then CT = SS; else CT=CT+0;  /* CT SS */
if _N_ = 6 then LinCT=SS; else LinCT=LinCT+0;
if _N_ = 7 then QuadCT=SS; else QuadCT=QuadCT+0;
if last then do;
  /*to find F and p-values for CT, Lin/Quad CT */
  CTMS=CT/dfCT;
  FCT=CTMS/div; pCT=1-probf(FCT,dfCT,dfE);
  LinCTMS=LinCT; QuadCTMS=QuadCT; /* df=1 here */
  FLinCT=LinCTMS/div; pLinCT=1-probf(FLinCT,1,dfE);
  FQuadCT=QuadCTMS/div; pQuadCT=1-probf(FQuadCT,1,dfE);
  file print;
  put ///'     (CT)SS = ' CT;
  put / '      (CT)MS = ' CTMS;
  put /'      F(CT) = ' FCT 'p-value = ' pCT;
  put ///'     (Linear CT)SS = ' LinCT;
  put / '      (Linear CT)MS = ' LinCTMS;
  put /'      F(LinCT) = ' FLinCT 'p-value = ' pLinCT;
  put ///'     (Quad CT)SS = ' QuadCT;
  put / '      (Quad CT)MS = ' QuadCTMS;
  put /'      F(Quad CT) = ' FQuadCT 'p-value = ' pQuadCT;
  output;
end;
run; /*Yes by Laura 23May2010*/

/*CT x Time pieces */
proc glm data=one outstat=junk33;
title1 "Split-Split pieces: TimexCT and Linear components";
class time CT;
model mc=time|CT/ss3;
contrast "Linear CT" CT -1 0 1;
contrast "LinearCT@Time1" CT -1 0 1 time*CT -1 0 1;
contrast "LinearCT@Time2" CT -1 0 1 time*CT 0 0 0 -1 0 1;
run;

proc print data=junk33;
title2 "Do we have <junk33>"; run; /*Yes by Laura 23May2010*/

/*Find Time x LinearCT Contrast*/
data splitsplit3;
set ER junk33;  /*merge Error a/b/c dataset with junk33 */
keep _SOURCE_ DF SS;
proc print;
title2 "Do we have <splitsplit3>"; run; /*Yes by Laura 23May2010*/
run; title2 ' ';

data splitsplit3; set splitsplit3 end=last;
title1 "Split-Split pieces: Time x CT and Linear contrasts";
retain div dfE dftime dftimeCT timeCT timeLinCT 0;
if _N_ = 3 then dfE=DF; else dfE=dfE+0;     /*This is Error(c) */
if _N_ = 3 then div=SS/DF; else div=div+0;
if _N_ = 5 then dftime=DF; else dftime=dftime+0;  /*df for timexLinCT*/
if _N_ = 7 then dftimeCT=DF; else dftimeCT=dftimeCT+0; /*df for timexCT */
if _N_ = 7 then timeCT=SS; else timeCT=timeCT+0; /*timexCT SS */
if _N_ < 8 then SS=0;
```

```
else if _N_ = 8 then SS=-SS;
timeLinCT=timeLinCT+SS;  /* timexLinCT SS */
if last then do;
  /*to find F and p-values for timexCT, timexLinCT */
  timeCTMS=timeCT/dftimeCT;
  FtimeCT=timeCTMS/div; ptimeCT=1-probf(FtimeCT,dftimeCT,dfE);
  timeLinCTMS=timeLinCT/dftime;
  FtimeLinCT=timeLinCTMS/div; ptimeLinCT=1-probf(FtimeLinCT,dftime,dfE);
  file print;
  put ///'     (timexCT)SS = ' timeCT;
  put / '      (timexCT)MS = ' timeCTMS;
  put /'      F(timexCT) = ' FtimeCT 'p-value = ' ptimeCT;
  put ///'     (time x LinearCT)SS = ' timeLinCT;
  put / '      (time x LinearCT)MS = ' timeLinCTMS;
  put /'      F(time x LinCT) = ' FtimeLinCT 'p-value = ' ptimeLinCT;
  output;
end;
run;

proc glm data=one outstat=junk34;
title1 "Split-Split pieces: timexCT Quadratic components";
class time CT;
model mc=time|CT/ss3;
contrast "Quadratic CT" CT -1 2 -1;
contrast "QuadraticCT@time1" CT -1 2 -1 time*CT -1 2 -1;
contrast "QuadraticCT@time2" CT -1 2 -1 time*CT 0 0 0 -1 2 -1;
run;

proc print data=junk34;
title2 "Do we have <junk34>"; run; /*Yes by Laura 23May2010*/

/*Find time x LinearCT Contrast*/
data splitsplit4;
set ER junk34;  /*merge Error a/b/c dataset with junk34 */
keep _SOURCE_ DF SS;
proc print;
title2 "Do we have <splitsplit4>"; run; /*Yes by Laura 23May2010*/
run; title2 ' ';

data splitsplit4; set splitsplit4 end=last;
title1 "Split-Split pieces: time x CT Quadratic contrasts";
retain div dfE dftime timeQuadCT 0;
if _N_ = 3 then dfE=DF; else dfE=dfE+0;     /*This is Error(c) */
if _N_ = 3 then div=SS/DF; else div=div+0;
if _N_ = 5 then dftime=DF; else dftime=dftime+0;  /*df for timexQuadCT*/
if _N_ < 8 then SS=0;
else if _N_ = 8 then SS=-SS;
timeQuadCT=timeQuadCT+SS;  /* timexQuadCT SS */
if last then do;
  /*to find F and p-values for timexQuadCT */
  timeQuadCTMS=timeQuadCT/dftime;
  FtimeQuadCT=timeQuadCTMS/div; ptimeQuadCT=1-probf(FtimeQuadCT,dftime,dfE);
  file print;
  put ///'     (time x QuadraticCT)SS = ' timeQuadCT;
  put / '      (time x QuadraticCT)MS = ' timeQuadCTMS;
  put /'      F(time x QuadraticCT) = ' FtimeQuadCT 'p-value = ' ptimeQuadCT;
  output;
```

```
end;
run;


/*CT x RT pieces */
proc glm data=one outstat=junk33;
title1 "Split-Split pieces: RTxCT and Linear components";
class RT CT;
model mc=RT|CT/ss3;
contrast "Linear CT" CT -1 0 1;
contrast "LinearCT@RT1" CT -1 0 1 RT*CT -1 0 1;
contrast "LinearCT@RT2" CT -1 0 1 RT*CT 0 0 0 -1 0 1;
run;

proc print data=junk33;
title2 "Do we have <junk33>"; run; /*Yes Laura 23May2010*/

/*Find RT x LinearCT Contrast*/
data splitsplit3;
set ER junk33;  /*merge Error a/b/c dataset with junk33 */
keep _SOURCE_ DF SS;
proc print;
title2 "Do we have <splitsplit3>"; run; /*Yes Laura 23May2010*/
run; title2 ' ';

data splitsplit3; set splitsplit3 end=last;
title1 "Split-Split pieces: RT x CT and Linear contrasts";
retain div dfE dfRT dfRTCT RTCT RTLinCT 0;
if _N_ = 3 then dfE=DF; else dfE=dfE+0;     /*This is Error(c) */
if _N_ = 3 then div=SS/DF; else div=div+0;
if _N_ = 5 then dfRT=DF; else dfRT=dfRT+0;  /*df for RTxLinCT*/
if _N_ = 7 then dfRTCT=DF; else dfRTCT=dfRTCT+0; /*df for RTxCT */
if _N_ = 7 then RTCT=SS; else RTCT=RTCT+0; /*RTxCT SS */
if _N_ < 8 then SS=0;
else if _N_ = 8 then SS=-SS;
RTLinCT=RTLinCT+SS;  /* RTxLinCT SS */
if last then do;
  /*to find F and p-values for RTxCT, RTxLinCT */
  RTCTMS=RTCT/dfRTCT;
  FRTCT=RTCTMS/div; pRTCT=1-probf(FRTCT,dfRTCT,dfE);
  RTLinCTMS=RTLinCT/dfRT;
  FRTLinCT=RTLinCTMS/div; pRTLinCT=1-probf(FRTLinCT,dfRT,dfE);
  file print;
  put ///'     (RTxCT)SS = ' RTCT;
  put / '      (RTxCT)MS = ' RTCTMS;
  put /'      F(RTxCT) = ' FRTCT 'p-value = ' pRTCT;
  put ///'     (RT x LinearCT)SS = ' RTLinCT;
  put / '      (RT x LinearCT)MS = ' RTLinCTMS;
  put /'      F(RT x LinCT) = ' FRTLinCT 'p-value = ' pRTLinCT;
  output;
end;
run;

proc glm data=one outstat=junk34;
title1 "Split-Split pieces: RTxCT Quadratic components";
class RT CT;
model mc=RT|CT/ss3;
```

```
contrast "Quadratic CT" CT -1 2 -1;
contrast "QuadraticCT@RT1" CT -1 2 -1 RT*CT -1 2 -1;
contrast "Quadratic@RT2" CT -1 2 -1 RT*CT 0 0 0 -1 2 -1;
run;

proc print data=junk34;
title2 "Do we have <junk34>"; run; /*Yes Laura 23May2010*/

/*Find RT x LinearCT Contrast*/
data splitsplit4;
set ER junk34;  /*merge Error a/b/c dataset with junk34 */
keep _SOURCE_ DF SS;
proc print;
title2 "Do we have <splitsplit4>"; run; /*Yes Laura 23May2010*/
run; title2 ' ';

data splitsplit4; set splitsplit4 end=last;
title1 "Split-Split pieces: RT x CT Quadratic contrasts";
retain div dfE dfRT RTQuadCT 0;
if _N_ = 3 then dfE=DF; else dfE=dfE+0;     /*This is Error(c) */
if _N_ = 3 then div=SS/DF; else div=div+0;
if _N_ = 5 then dfRT=DF; else dfRT=dfRT+0;  /*df for RTxQuadCT*/
if _N_ < 8 then SS=0;
else if _N_ = 8 then SS=-SS;
RTQuadCT=RTQuadCT+SS;  /* RTxQuadCT SS */
if last then do;
  /*to find F and p-values for RTxQuadCT */
  RTQuadCTMS=RTQuadCT/dfRT;
  FRTQuadCT=RTQuadCTMS/div; pRTQuadCT=1-probf(FRTQuadCT,dfRT,dfE);
  file print;
  put ///'     (RT x QuadraticCT)SS = ' RTQuadCT;
  put / '      (RT x QuadraticCT)MS = ' RTQuadCTMS;
  put /'      F(RT x QuadraticCT) = ' FRTQuadCT 'p-value = ' pRTQuadCT;
  output;
end;
run;

/*size RT time pieces */
proc glm data=one outstat=junk35;
title1 "Split-Split pieces: size, RT, time and Linear components";
class size RT time;
model mc=size|RT|time/ss3;
run;

proc print data=junk35;
title2 "Do we have <junk35>"; run; /*Yes Laura 23May2010*/

/*Find size x LinearTime Contrast*/
data splitsplit5;
set ER junk35;  /*merge Error a/b/c dataset with junk35 */
keep _SOURCE_ DF SS;
proc print;
title2 "Do we have <splitsplit5>"; run; /*Yes Laura 23May2010*/
run; title2 ' ';

data splitsplit5; set splitsplit5 end=last;
title1 "Split-Split pieces: size, RT, time and Linear contrasts";
```

```
retain div dfE dfS dfSRT dfStime dfSRTtime Size SRT Stime SRTtime 0;
if _N_ = 3 then dfE=DF; else dfE=dfE+0;     /*This is Error(c) */
if _N_ = 3 then div=SS/DF; else div=div+0;
if _N_ = 5 then dfS=DF; else dfS=dfS+0;  /*df for size*/
if _N_ = 5 then Size=SS; else Size=Size+0; /* Size SS */
if _N_ = 7 then dfSRT=DF; else dfSRT=dfSRT+0; /*df for sizexRT */
if _N_ = 7 then SRT=SS; else SRT=SRT+0; /*sizexRT SS */
if _N_ = 9 then dfStime=DF; else dfStime=dfStime+0;  /* size x time df */
if _N_ = 9 then Stime=SS; else Stime=Stime+0; /* sizexTime SS */
if _N_ = 11 then dfSRTtime=DF; else dfSRTtime=dfSRTtime+0;  /* df for
sizexRTxtime */
if _N_ = 11 then SRTtime=SS; else SRTtime=SRTtime+0;  /* size x RT x time SS
*/
if _N_ < 12 then SS=0;
else if _N_ = 12 then SS=-SS;
if last then do;
  /*to find F and p-values  */
  SizeMS=Size/dfS;
  FSize=SizeMS/div; pSize=1-probf(FSize,dfS,dfE);
  SRTMS= SRT/dfSRT;
  FSRT=SRTMS/div; pSRT=1-probf(FSRT,dfSRT,dfE);
  StimeMS=Stime/dfStime;
  FStime=StimeMS/div; pStime=1-probf(FStime,dfStime,dfE);
  SRTtimeMS=SRTtime/dfSRTtime;
  FSRTtime=SRTtimeMS/div; pSRTtime=1-probf(FSRTtime,dfSRTtime,dfE);
  file print;
  put ///'     (Size)SS  = ' Size;
  put / '      (Size)MS = ' SizeMS;
  put /'      F(Size) = ' FSize 'p-value = ' pSize;
  put///'      (SizexRT)SS  =  ' SRT;
  put/ '       (SizexRT)MS  =  ' SRTMS;
  put/ '      F(SizexRT)  =  ' FSRT ' p-value = ' pSRT;
  put///'      (SizexTime)SS = ' Stime;
  put/ '       (SizexTime)MS = ' StimeMS;
  put/ '      F(SizexTime)  =  ' FStime '  p-value = ' pStime;
  put///'       (SizexRTxTime)SS = ' SRTtime;
  put/'        (SizexRTxTime)MS = ' SRTtimeMS;
  put/ '      F(SizexRTxTime) = ' FSRTtime  '   p-value = ' pSRTtime;
  output;
end;
run;

/*size CT pieces */
proc glm data=one outstat=junk37;
title1 "Split-Split pieces: size CT Linear components";
class size CT;
model mc=size|CT/ss3;
contrast "Linear CT" CT -1 0 1;
contrast "LinCT@size1" CT -1 0 1 size*CT -1 0 1;
contrast "LinCT@size2" CT -1 0 1 size*CT 0 0 0 -1 0 1;
run;

proc print data=junk37;
title2 "Do we have <junk37>"; run; /*Yes Laura 23May2010*/

/*Find size x LinearCT Contrast*/
data splitsplit7;
```

```
set ER junk37;  /*merge Error a/b/c dataset with junk37 */
keep _SOURCE_ DF SS;
proc print;
title2 "Do we have <splitsplit7>"; run; /*Yes Laura 23May2010*/
run; title2 ' ';

data splitsplit7; set splitsplit7 end=last;
title1 "Split-Split pieces: size, CT Linear contrasts";
retain div dfE dfS dfSCT SCT SLinCT 0;
if _N_ = 3 then dfE=DF; else dfE=dfE+0;     /*This is Error(c) */
if _N_ = 3 then div=SS/DF; else div=div+0;
if _N_ = 5 then dfS=DF; else dfS=dfS+0;  /*df for SizexLinCT */
if _N_ = 7 then dfSCT=DF; else dfSCT=dfSCT+0; /*df for sizexCT */
if _N_ = 7 then SCT=SS; else SCT=SCT+0; /*sizexCT SS */
if _N_ < 8 then SS=0;
else if _N_ = 8 then SS=-SS;
SLinCT=SLinCT+SS;  /* sizexLinCT SS */
if last then do;
  /*to find F and p-values  */
  SCTMS= SCT/dfSCT;
  FSCT=SCTMS/div; pSCT=1-probf(FSCT,dfSCT,dfE);
  SLinCTMS=SLinCT/dfS;
  FSLinCT=SLinCTMS/div; pSLinCT=1-probf(FSLinCT,dfS,dfE);
  file print;
  put///'      (SizexCT)SS  =  ' SCT;
  put/ '       (SizexCT)MS  =  ' SCTMS;
  put/ '      F(SizexCT)  =  ' FSCT ' p-value = ' pSCT;
  put ///'     (Size x LinearCT)SS = ' SLinCT;
  put / '      (Size x LinearCT)MS = ' SLinCTMS;
  put /'      F(Size x LinearCT) = ' FSLinCT 'p-value = ' pSLinCT;
  output;
end;
run;

proc glm data=one outstat=junk38;
title1 "Split-Split pieces: size CT quadratic components";
class size CT;
model mc=size|CT/ss3;
contrast "Quadratic CT" CT -1 2 -1;
contrast "QuadCT@size1" CT -1 2 -1 size*CT -1 2 -1;
contrast "QuadCT@size2" CT -1 2 -1 size*CT 0 0 0 -1 2 -1;
run;

proc print data=junk38;
title2 "Do we have <junk38>"; run; /*Yes Laura 23May2010*/

/*Find size x Quadratic CT Contrast*/
data splitsplit8;
set ER junk38;  /*merge Error a/b/c dataset with junk38 */
keep _SOURCE_ DF SS;
proc print;
title2 "Do we have <splitsplit8>"; run; /*Yes Laura 23May2010*/
run; title2 ' ';
data splitsplit8; set splitsplit8 end=last;
title1 "Split-Split pieces: Size CT Quadratic contrasts";
retain div dfE dfS SQuadCT 0;
if _N_ = 3 then dfE=DF; else dfE=dfE+0;     /*This is Error(c) */
```

```
if _N_ = 3 then div=SS/DF; else div=div+0;
if _N_ = 5 then dfS=DF; else dfS=dfS+0;  /*df for SizexQuadCT*/
if _N_ < 8 then SS=0;
else if _N_ = 8 then SS=-SS;
SQuadCT=SQuadCT+SS;  /* SizexQuadCT SS */
if last then do;
  /*to find F and p-values for SizexQuadCT */
  SQuadCTMS=SQuadCT/dfS;
  FSQuadCT=SQuadCTMS/div; pSQuadCT=1-probf(FSQuadCT,dfS,dfE);
  file print;
  put ///'     (Size x Quad CT)SS = ' SQuadCT;
  put / '      (Size x Quad CT)MS = ' SQuadCTMS;
  put /'      F(Size x Quad CT) = ' FSQuadCT 'p-value = ' pSQuadCT;
  output;
end;
run;



/*abrade CT pieces */
proc glm data=one outstat=junk39;
title1 "Split-Split pieces: abrade CT Linear components";
class abrade CT;
model mc=abrade|CT/ss3;
contrast "Linear CT" CT -1 0 1;
contrast "LinCT@abrade1" CT -1 0 1 abrade*CT -1 0 1;
contrast "LinCT@abrade2" CT -1 0 1 abrade*CT 0 0 0 -1 0 1;
run;

proc print data=junk39;
title2 "Do we have <junk39>"; run; /*Yes Laura 23May2010*/

/*Find size x LinearCT Contrast*/
data splitsplit9;
set ER junk39;  /*merge Error a/b/c dataset with junk39 */
keep _SOURCE_ DF SS;
proc print;
title2 "Do we have <splitsplit9>"; run; /*Yes Laura 23May2010*/
run; title2 ' ';

data splitsplit9; set splitsplit9 end=last;
title1 "Split-Split pieces: Abrade, CT Linear contrasts";
retain div dfE dfAb dfAbCT Ab AbCT AbLinCT 0;
if _N_ = 3 then dfE=DF; else dfE=dfE+0;     /*This is Error(c) */
if _N_ = 3 then div=SS/DF; else div=div+0;
if _N_ = 5 then dfAb=DF; else dfAb=dfAb+0;  /*df for AbradexLinCT, and Abrade
*/
if _N_ = 5 then Ab=SS; else Ab=Ab+0;  /*Abrade SS*/
if _N_ = 7 then dfAbCT=DF; else dfAbCT=dfAbCT+0; /*df for AbradexCT */
if _N_ = 7 then AbCT=SS; else AbCT=AbCT+0; /*AbradexCT SS */
if _N_ < 8 then SS=0;
else if _N_ = 8 then SS=-SS;
AbLinCT=AbLinCT+SS;  /* abradexLinCT SS */
if last then do;
  /*to find F and p-values  */
  AbMS=Ab/dfAb;
  FAb=AbMS/div; pAb=1-probf(FAb,dfAb,dfE);
```

```
  AbCTMS= AbCT/dfAbCT;
  FAbCT=AbCTMS/div; pAbCT=1-probf(FAbCT,dfAbCT,dfE);
  AbLinCTMS=AbLinCT/dfAb;
  FAbLinCT=AbLinCTMS/div; pAbLinCT=1-probf(FAbLinCT,dfAb,dfE);
  file print;
  put///'      (Abrade)SS = ' Ab;
  put/ '       (Abrade)MS = ' AbMS;
  put/ '      F(Abrade) = ' FAb '   p-value = ' pAb;
  put///'      (AbradexCT)SS  =  ' AbCT;
  put/ '       (AbradexCT)MS  =  ' AbCTMS;
  put/ '      F(AbradexCT)  =  ' FAbCT ' p-value = ' pAbCT;
  put ///'     (Abrade x LinearCT)SS = ' AbLinCT;
  put / '      (Abrade x LinearCT)MS = ' AbLinCTMS;
  put /'      F(Abrade x LinearCT) = ' FAbLinCT 'p-value = ' pAbLinCT;
  output;
end;
run;

proc glm data=one outstat=junk310;
title1 "Split-Split pieces: Abrade CT quadratic components";
class abrade CT;
model mc=abrade|CT/ss3;
contrast "Quadratic CT" CT -1 2 -1;
contrast "QuadCT@abrade1" CT -1 2 -1 abrade*CT -1 2 -1;
contrast "QuadCT@abrade2" CT -1 2 -1 abrade*CT 0 0 0 -1 2 -1;
run;

proc print data=junk310;
title2 "Do we have <junk310>"; run; /*Yes Laura 23May2010*/

/*Find abrade x Quadratic CT Contrast*/
data splitsplit10;
set ER junk310;  /*merge Error a/b/c dataset with junk310 */
keep _SOURCE_ DF SS;
proc print;
title2 "Do we have <splitsplit10>"; run; /*Yes Laura 23May2010*/
run; title2 ' ';
data splitsplit10; set splitsplit10 end=last;
title1 "Split-Split pieces: abrade CT Quadratic contrasts";
retain div dfE dfAb AbQuadCT 0;
if _N_ = 3 then dfE=DF; else dfE=dfE+0;     /*This is Error(c) */
if _N_ = 3 then div=SS/DF; else div=div+0;
if _N_ = 5 then dfAb=DF; else dfAb=dfAb+0;  /*df for abradexQuadCT*/
if _N_ < 8 then SS=0;
else if _N_ = 8 then SS=-SS;
AbQuadCT=AbQuadCT+SS;  /* abradexQuadCT SS */
if last then do;
  /*to find F and p-values for abradexQuadCT */
  AbQuadCTMS=AbQuadCT/dfAb;
  FAbQuadCT=AbQuadCTMS/div; pAbQuadCT=1-probf(FAbQuadCT,dfAb,dfE);
  file print;
  put ///'     (abrade x Quad CT)SS = ' AbQuadCT;
  put / '      (abrade x Quad CT)MS = ' AbQuadCTMS;
  put /'      F(abrade x Quad CT) = ' FAbQuadCT 'p-value = ' pAbQuadCT;
  output;
end;
run;
```

```
/*abrade time pieces */
proc glm data=one outstat=junk311;
title1 "Split-Split pieces: abrade time Linear components";
class abrade time;
model mc=abrade|time/ss3;
run;

proc print data=junk311;
title2 "Do we have <junk311>"; run; /*Yes*/

/*Find abrade x Time */
data splitsplit11;
set ER junk311;  /*merge Error a/b/c dataset with junk311 */
keep _SOURCE_ DF SS;
proc print;
title2 "Do we have <splitsplit11>"; run; /*Yes*/
run; title2 ' ';

data splitsplit11; set splitsplit11 end=last;
title1 "Split-Split pieces: Abrade, time";
retain div dfE dfAb dfAbT AbT 0;
if _N_ = 3 then dfE=DF; else dfE=dfE+0;     /*This is Error(c) */
if _N_ = 3 then div=SS/DF; else div=div+0;
if _N_ = 5 then dfAb=DF; else dfAb=dfAb+0;  /*df for Abrade */
if _N_ = 7 then dfAbT=DF; else dfAbT=dfAbT+0; /*df for AbradexT */
if _N_ = 7 then AbT=SS; else AbT=AbT+0; /*AbradexT SS */
if _N_ < 8 then SS=0;
else if _N_ = 8 then SS=-SS;
if last then do;
  /*to find F and p-values  */
  AbTMS= AbT/dfAbT;
  FAbT=AbTMS/div; pAbT=1-probf(FAbT,dfAbT,dfE);
  file print;
  put///'      (AbradexTime)SS  =  ' AbT;
  put/ '       (AbradexTime)MS  =  ' AbTMS;
  put/ '      F(AbradexTime)  =  ' FAbT ' p-value = ' pAbT;
  output;
end;
run;

/*The rest of the story... pieces */
proc glm data=one outstat=junk313;
title1 "Split-Split pieces: not previously covered";
class CT RT time size abrade;
model mc=CT*RT*time size*RT size*CT*time size*RT*time size*CT*RT
size*CT*RT*time
   abrade*RT abrade*RT*time abrade*CT*time abrade*CT*RT  abrade*CT*RT*time
   abrade*size abrade*size*time abrade*size*RT abrade*size*RT*time
   abrade*size*CT abrade*size*CT*time abrade*size*CT*RT
   abrade*size*CT*RT*time/ss3;

run;

proc print data=junk313;
title2 "Do we have <junk313>"; run; /*Yes*/
```

```
/*Find rest of pieces*/
data splitsplit13;
set junk313 ER;  /*merge Error a/b/c dataset with junk313 */
keep _SOURCE_ DF SS; output;
proc print;
title2 "Do we have <splitsplit13>"; run; /*Yes*/
run; title2 ' ';

proc iml;
use splitsplit13;
read all var {DF SS} into P;
nr=nrow(P);
FM=J(nr,5,0);
FM[1:nr,1:2]=P[1:nr,1:2];
do r = 1 to nr;
    FM[r,3]=FM[r,2]/FM[r,1];
end;
MSEc=FM[nr,3]; dfE=FM[nr,1];
/*print P FM MSEc; */
do r = 1 to nr;
    FM[r,4]=FM[r,3]/MSEc;
      FM[r,5]=1-probf(FM[r,4],FM[r,1],dfE);
end;
/*print MSEc dfE FM; */
varnames={DF SS MS F p};
create outFP from FM (|colname=varnames|);
append from FM;
run;

data yes;
merge splitsplit13 outFP;
proc print data=yes;
title2 "The rest of the F and p values"; run;
quit;
```

MOISTURE CONTENT OUTPUT FROZEN

Batch Vacuum-belt Drying Analysis 23 May 2010 1

The GLM Procedure

Class Level Information

Class	Levels	Values
rep	6	1 2 3 4 5 6
abrade	2	1 2
size	2	1 2
CT	3	1 2 3

RT 2 1 2

time 2 1 2

Number of Observations Read 288
Number of Observations Used 288

Batch Vacuum-belt Drying Analysis 23 May 2010 2

The GLM Procedure

Dependent Variable: mc

Source	DF	Sum of Squares	Mean Square	F Value
Model	287	5.02037844	0.01749261	.
Error	0	0.00000000	.	
Corrected Total	287	5.02037844		

Source	Pr > F
Model	.
Error	
Corrected Total	

R-Square	Coeff Var	Root MSE	mc Mean
1.000000	.	.	0.096611

Source	DF	Type III SS	Mean Square	F Value
time	1	0.20693889	0.20693889	.
RT	1	0.00001513	0.00001513	.
RT*time	1	0.00105035	0.00105035	.
CT	2	1.36183401	0.68091700	.
CT*time	2	0.13195334	0.06597667	.
CT*RT	2	0.18784515	0.09392257	.
CT*RT*time	2	0.02865651	0.01432825	.
size	1	0.00880022	0.00880022	.
size*time	1	0.00001800	0.00001800	.

Source	Pr > F
time	.
RT	.
RT*time	.
CT	.
CT*time	.
CT*RT	.
CT*RT*time	.
size	.
size*time	.

Batch Vacuum-belt Drying Analysis 23 May 2010 3

The GLM Procedure

Dependent Variable: mc

Source	DF	Type III SS	Mean Square	F Value
size*RT	1	0.03087612	0.03087612	.
size*RT*time	1	0.00567112	0.00567112	.
size*CT	2	0.07014442	0.03507221	.
size*CT*time	2	0.01618106	0.00809053	.
size*CT*RT	2	0.00970640	0.00485320	.
size*CT*RT*time	2	0.00935040	0.00467520	.
abrade	1	0.01817689	0.01817689	.
abrade*time	1	0.00961422	0.00961422	.
abrade*RT	1	0.00076701	0.00076701	.
abrade*RT*time	1	0.04841235	0.04841235	.
abrade*CT	2	0.01515284	0.00757642	.
abrade*CT*time	2	0.07568992	0.03784496	.
abrade*CT*RT	2	0.00490942	0.00245471	.
abrade*CT*RT*time	2	0.08290609	0.04145305	.
abrade*size	1	0.00261606	0.00261606	.
abrade*size*time	1	0.06324939	0.06324939	.
abrade*size*RT	1	0.01010568	0.01010568	.
abrade*size*RT*time	1	0.00886668	0.00886668	.
abrade*size*CT	2	0.01613401	0.00806700	.
abrade*size*CT*time	2	0.02784284	0.01392142	.
abrade*size*CT*RT	2	0.04523826	0.02261913	.
abra*size*CT*RT*time	2	0.00815667	0.00407834	.
rep	5	0.20677757	0.04135551	.
rep*time	5	0.01874965	0.00374993	.
rep*RT	5	0.03008700	0.00601740	.

rep*RT*time	5	0.03007419	0.00601484 .
rep*CT	10	0.26848424	0.02684842 .
rep*CT*time	10	0.04557149	0.00455715 .
rep*CT*RT	10	0.10546760	0.01054676 .
rep*CT*RT*time	10	0.03666583	0.00366658 .
rep*size	5	0.07792332	0.01558466 .
rep*size*time	5	0.01548729	0.00309746 .
rep*size*RT	5	0.01389542	0.00277908 .
rep*size*RT*time	5	0.04749217	0.00949843 .
rep*size*CT	10	0.09963741	0.00996374 .
rep*size*CT*time	10	0.11474752	0.01147475 .
rep*size*CT*RT	10	0.08683744	0.00868374 .
rep*size*CT*RT*time	10	0.08385819	0.00838582 .
rep*abrade	5	0.03051040	0.00610208 .
rep*abrade*time	5	0.03271032	0.00654206 .
rep*abrade*RT	5	0.07468111	0.01493622 .
rep*abrade*RT*time	5	0.05452436	0.01090487 .
rep*abrade*CT	10	0.02760249	0.00276025 .
rep*abrade*CT*time	10	0.24963066	0.02496307 .
rep*abrade*CT*RT	10	0.10973158	0.01097316 .
rep*abrad*CT*RT*time	10	0.16026383	0.01602638 .

Batch Vacuum-belt Drying Analysis 23 May 2010 4

The GLM Procedure

Dependent Variable: mc

Source	Pr > F
size*RT	.
size*RT*time	.
size*CT	.
size*CT*time	.
size*CT*RT	.
size*CT*RT*time	.
abrade	.
abrade*time	.
abrade*RT	.
abrade*RT*time	.
abrade*CT	.
abrade*CT*time	.
abrade*CT*RT	.
abrade*CT*RT*time	.
abrade*size	.
abrade*size*time	.

abrade*size*RT .
abrade*size*RT*time .
abrade*size*CT .
abrade*size*CT*time .
abrade*size*CT*RT .
abra*size*CT*RT*time .
rep .
rep*time .
rep*RT .
rep*RT*time .
rep*CT .
rep*CT*time .
rep*CT*RT .
rep*CT*RT*time .
rep*size .
rep*size*time .
rep*size*RT .
rep*size*RT*time .
rep*size*CT .
rep*size*CT*time .
rep*size*CT*RT .
rep*size*CT*RT*time .
rep*abrade .
rep*abrade*time .
rep*abrade*RT .
rep*abrade*RT*time .
rep*abrade*CT .
rep*abrade*CT*time .
rep*abrade*CT*RT .
rep*abrad*CT*RT*time .

Batch Vacuum-belt Drying Analysis 23 May 2010 5

The GLM Procedure

Dependent Variable: mc

Source	DF	Type III SS	Mean Square	F Value
rep*abrade*size	5	0.02475899	0.00495180	.
rep*abrade*size*time	5	0.09142324	0.01828465	.
rep*abrade*size*RT	5	0.08178419	0.01635684	.
rep*abr*size*RT*time	5	0.04095711	0.00819142	.
rep*abrade*size*CT	10	0.02799808	0.00279981	.

rep*abr*size*CT*time	10	0.12792066	0.01279207	.
rep*abrad*size*CT*RT	10	0.03141799	0.00314180	.
re*abr*siz*CT*RT*tim	10	0.06582766	0.00658277	.

Source	Pr > F
rep*abrade*size	.
rep*abrade*size*time	.
rep*abrade*size*RT	.
rep*abr*size*RT*time	.
rep*abrade*size*CT	.
rep*abr*size*CT*time	.
rep*abrad*size*CT*RT	.
re*abr*siz*CT*RT*tim	.

RT qual, Time qualitative; SOURCE, DF & SS data only....contrasts 7

Obs	_SOURCE_	DF	SS
1	ERROR	0	0.00000
2	time	1	0.20694
3	RT	1	0.00002
4	RT*time	1	0.00105
5	CT	2	1.36183
6	CT*time	2	0.13195
7	CT*RT	2	0.18785
8	CT*RT*time	2	0.02866
9	size	1	0.00880
10	size*time	1	0.00002
11	size*RT	1	0.03088
12	size*RT*time	1	0.00567
13	size*CT	2	0.07014
14	size*CT*time	2	0.01618
15	size*CT*RT	2	0.00971
16	size*CT*RT*time	2	0.00935
17	abrade	1	0.01818
18	abrade*time	1	0.00961
19	abrade*RT	1	0.00077
20	abrade*RT*time	1	0.04841
21	abrade*CT	2	0.01515
22	abrade*CT*time	2	0.07569
23	abrade*CT*RT	2	0.00491
24	abrade*CT*RT*time	2	0.08291
25	abrade*size	1	0.00262
26	abrade*size*time	1	0.06325
27	abrade*size*RT	1	0.01011

Obs	_SOURCE_	DF	SS
28	abrade*size*RT*time	1	0.00887
29	abrade*size*CT	2	0.01613
30	abrade*size*CT*time	2	0.02784
31	abrade*size*CT*RT	2	0.04524
32	abra*size*CT*RT*time	2	0.00816
33	rep	5	0.20678
34	rep*time	5	0.01875
35	rep*RT	5	0.03009
36	rep*RT*time	5	0.03007
37	rep*CT	10	0.26848
38	rep*CT*time	10	0.04557
39	rep*CT*RT	10	0.10547
40	rep*CT*RT*time	10	0.03667
41	rep*size	5	0.07792
42	rep*size*time	5	0.01549
43	rep*size*RT	5	0.01390
44	rep*size*RT*time	5	0.04749
45	rep*size*CT	10	0.09964
46	rep*size*CT*time	10	0.11475
47	rep*size*CT*RT	10	0.08684
48	rep*size*CT*RT*time	10	0.08386
49	rep*abrade	5	0.03051
50	rep*abrade*time	5	0.03271

RT qual, Time qualitative; SOURCE, DF & SS data only....contrasts 8

Obs	_SOURCE_	DF	SS
51	rep*abrade*RT	5	0.07468
52	rep*abrade*RT*time	5	0.05452
53	rep*abrade*CT	10	0.02760
54	rep*abrade*CT*time	10	0.24963
55	rep*abrade*CT*RT	10	0.10973
56	rep*abrad*CT*RT*time	10	0.16026
57	rep*abrade*size	5	0.02476
58	rep*abrade*size*time	5	0.09142
59	rep*abrade*size*RT	5	0.08178
60	rep*abr*size*RT*time	5	0.04096
61	rep*abrade*size*CT	10	0.02800
62	rep*abr*size*CT*time	10	0.12792
63	rep*abrad*size*CT*RT	10	0.03142
64	re*abr*siz*CT*RT*tim	10	0.06583

RT qual, Time qualitative; SOURCE, DF & SS data only....contrasts 9

ER	EC

5 0.0187497 10 0.2684842
10 0.0601612 10 0.0455715
220 2.2278106 10 0.1054676
10 0.0366658
5 0.0779233
5 0.0154873
5 0.0138954
5 0.0474922
10 0.0996374
10 0.1147475
10 0.0868374
10 0.0838582
5 0.0305104
5 0.0327103
5 0.0746811
5 0.0545244
10 0.0276025
10 0.2496307
10 0.1097316
10 0.1602638
5 0.024759
5 0.0914232
5 0.0817842
5 0.0409571
10 0.0279981
10 0.1279207
10 0.031418
10 0.0658277

Is this two2 10

Obs	_SOURCE_	DF	SS
1	ERROR	0	0.00000
2	time	1	0.20694
3	RT	1	0.00002
4	RT*time	1	0.00105
5	CT	2	1.36183
6	CT*time	2	0.13195
7	CT*RT	2	0.18785
8	CT*RT*time	2	0.02866
9	size	1	0.00880
10	size*time	1	0.00002
11	size*RT	1	0.03088
12	size*RT*time	1	0.00567

13	size*CT	2	0.07014
14	size*CT*time	2	0.01618
15	size*CT*RT	2	0.00971
16	size*CT*RT*time	2	0.00935
17	abrade	1	0.01818
18	abrade*time	1	0.00961
19	abrade*RT	1	0.00077
20	abrade*RT*time	1	0.04841
21	abrade*CT	2	0.01515
22	abrade*CT*time	2	0.07569
23	abrade*CT*RT	2	0.00491
24	abrade*CT*RT*time	2	0.08291
25	abrade*size	1	0.00262
26	abrade*size*time	1	0.06325
27	abrade*size*RT	1	0.01011
28	abrade*size*RT*time	1	0.00887
29	abrade*size*CT	2	0.01613
30	abrade*size*CT*time	2	0.02784
31	abrade*size*CT*RT	2	0.04524
32	abra*size*CT*RT*time	2	0.00816
33	rep	5	0.20678
34	rep*time	5	0.01875
35	rep*RT	5	0.03009
36	rep*RT*time	5	0.03007
37	rep*CT	10	0.26848
38	rep*CT*time	10	0.04557
39	rep*CT*RT	10	0.10547
40	rep*CT*RT*time	10	0.03667
41	rep*size	5	0.07792
42	rep*size*time	5	0.01549
43	rep*size*RT	5	0.01390
44	rep*size*RT*time	5	0.04749
45	rep*size*CT	10	0.09964
46	rep*size*CT*time	10	0.11475
47	rep*size*CT*RT	10	0.08684
48	rep*size*CT*RT*time	10	0.08386
49	rep*abrade	5	0.03051
50	rep*abrade*time	5	0.03271

Is this two2 11

Obs	_SOURCE_	DF	SS
51	rep*abrade*RT	5	0.07468
52	rep*abrade*RT*time	5	0.05452
53	rep*abrade*CT	10	0.02760

54	rep*abrade*CT*time	10	0.24963
55	rep*abrade*CT*RT	10	0.10973
56	rep*abrad*CT*RT*time	10	0.16026
57	rep*abrade*size	5	0.02476
58	rep*abrade*size*time	5	0.09142
59	rep*abrade*size*RT	5	0.08178
60	rep*abr*size*RT*time	5	0.04096
61	rep*abrade*size*CT	10	0.02800
62	rep*abr*size*CT*time	10	0.12792
63	rep*abrad*size*CT*RT	10	0.03142
64	re*abr*siz*CT*RT*tim	10	0.06583
65	ERRORA	5	0.01875
66	ERRORB	10	0.06016
67	ERRORC	220	2.22781

Whole Plot pieces: Time and reps 12

The GLM Procedure

Class Level Information

Class	Levels	Values
time	2	1 2
rep	6	1 2 3 4 5 6

Number of Observations Read 288
Number of Observations Used 288

Whole Plot pieces: Time and reps 13

The GLM Procedure

Dependent Variable: mc

Source	DF	Sum of Squares	Mean Square	F Value
Model	11	0.43246611	0.03931510	2.37
Error	276	4.58791233	0.01662287	
Corrected Total	287	5.02037844		

Source Pr > F

Model 0.0083

Error

Corrected Total

R-Square	Coeff Var	Root MSE	mc Mean
0.086142	133.4523	0.128930	0.096611

Source	DF	Type III SS	Mean Square	F Value
time	1	0.20693889	0.20693889	12.45
rep	5	0.20677757	0.04135551	2.49
time*rep	5	0.01874965	0.00374993	0.23

Source	Pr > F
time	0.0005
rep	0.0317
time*rep	0.9513

Whole Plot pieces: Time and reps 14
Do we have <junk1>

Obs	_NAME_	_SOURCE_	_TYPE_	DF	SS	F	PROB
1	mc	ERROR	ERROR	276	4.58791	.	.
2	mc	time	SS3	1	0.20694	12.4490	0.00049
3	mc	rep	SS3	5	0.20678	2.4879	0.03173
4	mc	time*rep	SS3	5	0.01875	0.2256	0.95126

Whole Plot pieces: Time and reps 15
Do we have <wholeplot>

Obs	DF	SS	_SOURCE_
1	5	0.01875	ERRORA
2	10	0.06016	ERRORB
3	220	2.22781	ERRORC
4	276	4.58791	ERROR
5	1	0.20694	time
6	5	0.20678	rep
7	5	0.01875	time*r

Whole Plot pieces: Time, Rep 16

(time)SS = 0.2069388889

(time)MS = 0.2069388889

F(time) = 55.184725643 p-value = 0.0006965127

(rep)SS = 0.2067775694

(rep)MS = 0.0413555139

F(rep) = 11.028341266 p-value = 0.0098778152

Split plot pieces: RT, RTxTime 17

The GLM Procedure

Class Level Information

Class	Levels	Values
RT	2	1 2
time	2	1 2

Number of Observations Read 288
Number of Observations Used 288

Split plot pieces: RT, RTxTime 18

The GLM Procedure

Dependent Variable: mc

Source	DF	Sum of Squares	Mean Square	F Value
Model	3	0.20800436	0.06933479	4.09
Error	284	4.81237408	0.01694498	
Corrected Total	287	5.02037844		

Source Pr > F

Model 0.0073

Error

Corrected Total

R-Square	Coeff Var	Root MSE	mc Mean
0.041432	134.7390	0.130173	0.096611

Source	DF	Type III SS	Mean Square	F Value
RT	1	0.00001513	0.00001513	0.00
time	1	0.20693889	0.20693889	12.21
RT*time	1	0.00105035	0.00105035	0.06

Source	Pr > F
RT	0.9762
time	0.0006
RT*time	0.8036

Do we have <junk2> 19

Obs	_NAME_	_SOURCE_	_TYPE_	DF	SS	F	PROB
1	mc	ERROR	ERROR	284	4.81237	.	.
2	mc	RT	SS3	1	0.00002	0.0009	0.97619
3	mc	time	SS3	1	0.20694	12.2124	0.00055
4	mc	RT*time	SS3	1	0.00105	0.0620	0.80356

Do we have <junk2> 20
Do we have <split1>

Obs	DF	SS	_SOURCE_
1	5	0.01875	ERRORA
2	10	0.06016	ERRORB
3	220	2.22781	ERRORC
4	284	4.81237	ERROR
5	1	0.00002	RT
6	1	0.20694	time
7	1	0.00105	RT*tim

Split Plot pieces: RT, RT*Time and Linear contrasts 21

(RT)SS = 0.000015125

(RT)MS = 0.000015125

F(RT) = 0.0025140791 p-value = 0.9609977259

(RTxTime)SS = 0.0010503472

(RTxTime)MS = 0.0010503472

F(RTxTime) = 0.1745888246 p-value = 0.6848956319

Split-Split pieces: CT, and CT contrasts 22

The GLM Procedure

Class Level Information

Class	Levels	Values
CT	3	1 2 3

Number of Observations Read 288
Number of Observations Used 288

Split-Split pieces: CT, and CT contrasts 23

The GLM Procedure

Dependent Variable: mc

Source	DF	Sum of Squares	Mean Square	F Value
Model	2	1.36183401	0.68091700	53.04
Error	285	3.65854444	0.01283700	
Corrected Total	287	5.02037844		

Source	Pr > F
Model	<.0001
Error	

Corrected Total

R-Square	Coeff Var	Root MSE	mc Mean
0.271261	117.2748	0.113300	0.096611

Source	DF	Type III SS	Mean Square	F Value
CT	2	1.36183401	0.68091700	53.04

Source	Pr > F
CT	<.0001

Contrast	DF	Contrast SS	Mean Square	F Value
Linear CT	1	1.27775817	1.27775817	99.54
Quad CT	1	0.08407584	0.08407584	6.55

Contrast	Pr > F
Linear CT	<.0001
Quad CT	0.0110

Split-Split pieces: CT, and CT contrasts 24
Do we have <junk3> 21:55 Sunday, May 22, 2005

Obs	_NAME_	_SOURCE_	_TYPE_	DF	SS	F	PROB
1	mc	ERROR	ERROR	285	3.65854	.	.
2	mc	CT	SS3	2	1.36183	53.0433	0.000000
3	mc	Linear CT	CONTRAST	1	1.27776	99.5371	0.000000
4	mc	Quad CT	CONTRAST	1	0.08408	6.5495	0.011008

Split-Split pieces: CT, and CT contrasts 25
Do we have <splitsplit>

Obs	DF	SS	_SOURCE_
1	5	0.01875	ERRORA
2	10	0.06016	ERRORB
3	220	2.22781	ERRORC
4	285	3.65854	ERROR
5	2	1.36183	CT
6	1	1.27776	Linear

7 1 0.08408 Quad C

Split-Split pieces: CT, and CT contrasts 26

(CT)SS = 1.3618340069

(CT)MS = 0.6809170035

F(CT) = 67.241686472 p-value = 0

(Linear CT)SS = 1.2777581719

(Linear CT)MS = 1.2777581719

F(LinCT) = 126.18074441 p-value = 0

(Quad CT)SS = 0.0840758351

(Quad CT)MS = 0.0840758351

F(Quad CT) = 8.302628533 p-value = 0.0043506328

Split-Split pieces: TimexCT and Linear components 27

The GLM Procedure

Class Level Information

Class	Levels	Values
time	2	1 2
CT	3	1 2 3

Number of Observations Read 288
Number of Observations Used 288

Split-Split pieces: TimexCT and Linear components 28

The GLM Procedure

Dependent Variable: mc

Source	DF	Sum of Squares	Mean Square	F Value

Model 5 1.70072624 0.34014525 28.89

Error 282 3.31965221 0.01177182

Corrected Total 287 5.02037844

Source	Pr > F
Model	<.0001
Error	
Corrected Total	

R-Square	Coeff Var	Root MSE	mc Mean
0.338765	112.3039	0.108498	0.096611

Source	DF	Type III SS	Mean Square	F Value
time	1	0.20693889	0.20693889	17.58
CT	2	1.36183401	0.68091700	57.84
time*CT	2	0.13195334	0.06597667	5.60

Source	Pr > F
time	<.0001
CT	<.0001
time*CT	0.0041

Contrast	DF	Contrast SS	Mean Square	F Value
Linear CT	1	1.27775817	1.27775817	108.54
LinearCT@Time1	1	1.10017426	1.10017426	93.46
LinearCT@Time2	1	0.30217704	0.30217704	25.67

Contrast	Pr > F
Linear CT	<.0001
LinearCT@Time1	<.0001
LinearCT@Time2	<.0001

Split-Split pieces: TimexCT and Linear components 29
Do we have <junk33>

Obs	_NAME_	_SOURCE_	_TYPE_	DF	SS	F	PROB

1	mc	ERROR	ERROR	282	3.31965	.	.
2	mc	time	SS3	1	0.20694	17.579	.000036931
3	mc	CT	SS3	2	1.36183	57.843	8.9114E-22
4	mc	time*CT	SS3	2	0.13195	5.605	.004102715
5	mc	Linear CT	CONTRAST	1	1.27776	108.544	1.0239E-21
6	mc	LinearCT@Time1	CONTRAST	1	1.10017	93.458	2.7914E-19
7	mc	LinearCT@Time2	CONTRAST	1	0.30218	25.670	.000000734

Split-Split pieces: TimexCT and Linear components 30

Do we have <splitsplit3>

Obs	DF	SS	_SOURCE_
1	5	0.01875	ERRORA
2	10	0.06016	ERRORB
3	220	2.22781	ERRORC
4	282	3.31965	ERROR
5	1	0.20694	time
6	2	1.36183	CT
7	2	0.13195	time*C
8	1	1.27776	Linear
9	1	1.10017	Linear
10	1	0.30218	Linear

Split-Split pieces: Time x CT and Linear contrasts 31

(timexCT)SS = 0.1319533403

(timexCT)MS = 0.0659766701

F(timexCT) = 6.5153058968 p-value = 0.0017826562

(time x LinearCT)SS = 0.1245931302

(time x LinearCT)MS = 0.1245931302

F(time x LinCT) = 12.303778809 p-value = 0.0005479469

Split-Split pieces: timexCT Quadratic components 32

The GLM Procedure

Class Level Information

Class	Levels	Values

time	2	1 2
CT	3	1 2 3

Number of Observations Read	288
Number of Observations Used	288

Split-Split pieces: timexCT Quadratic components 33

The GLM Procedure

Dependent Variable: mc

Source	DF	Sum of Squares	Mean Square	F Value
Model	5	1.70072624	0.34014525	28.89
Error	282	3.31965221	0.01177182	
Corrected Total	287	5.02037844		

Source	Pr > F
Model	<.0001
Error	
Corrected Total	

R-Square	Coeff Var	Root MSE	mc Mean
0.338765	112.3039	0.108498	0.096611

Source	DF	Type III SS	Mean Square	F Value
time	1	0.20693889	0.20693889	17.58
CT	2	1.36183401	0.68091700	57.84
time*CT	2	0.13195334	0.06597667	5.60

Source	Pr > F
time	<.0001
CT	<.0001
time*CT	0.0041

Contrast	DF	Contrast SS	Mean Square	F Value
Quadratic CT	1	0.08407584	0.08407584	7.14
QuadraticCT@time1	1	0.07059403	0.07059403	6.00
QuadraticCT@time2	1	0.02084201	0.02084201	1.77

Contrast	Pr > F
Quadratic CT	0.0080
QuadraticCT@time1	0.0149
QuadraticCT@time2	0.1844

Split-Split pieces: timexCT Quadratic components 34
Do we have <junk34>

Obs	_NAME_	_SOURCE_	_TYPE_	DF	SS	F	PROB
1	mc	ERROR	ERROR	282	3.31965	.	.
2	mc	time	SS3	1	0.20694	17.5792	0.00004
3	mc	CT	SS3	2	1.36183	57.8430	0.00000
4	mc	time*CT	SS3	2	0.13195	5.6046	0.00410
5	mc	Quadratic CT	CONTRAST	1	0.08408	7.1421	0.00797
6	mc	QuadraticCT@time1	CONTRAST	1	0.07059	5.9969	0.01494
7	mc	QuadraticCT@time2	CONTRAST	1	0.02084	1.7705	0.18440

Split-Split pieces: timexCT Quadratic components 35
Do we have <splitsplit4>

Obs	DF	SS	_SOURCE_
1	5	0.01875	ERRORA
2	10	0.06016	ERRORB
3	220	2.22781	ERRORC
4	282	3.31965	ERROR
5	1	0.20694	time
6	2	1.36183	CT
7	2	0.13195	time*C
8	1	0.08408	Quadra
9	1	0.07059	Quadra
10	1	0.02084	Quadra

Split-Split pieces: time x CT Quadratic contrasts 36

(time x QuadraticCT)SS = 0.0073602101

(time x QuadraticCT)MS = 0.0073602101

F(time x QuadraticCT) = 0.7268329845 p-value = 0.3948388368

Split-Split pieces: RTxCT and Linear components 37

The GLM Procedure

Class Level Information

Class	Levels	Values
RT	2	1 2
CT	3	1 2 3

Number of Observations Read 288
Number of Observations Used 288

Split-Split pieces: RTxCT and Linear components 38

The GLM Procedure

Dependent Variable: mc

Source	DF	Sum of Squares	Mean Square	F Value
Model	5	1.54969428	0.30993886	25.18
Error	282	3.47068417	0.01230739	
Corrected Total	287	5.02037844		

Source	Pr > F
Model	<.0001
Error	
Corrected Total	

R-Square	Coeff Var	Root MSE	mc Mean
0.308681	114.8301	0.110939	0.096611

Source	DF	Type III SS	Mean Square	F Value
RT	1	0.00001513	0.00001513	0.00
CT	2	1.36183401	0.68091700	55.33
RT*CT	2	0.18784515	0.09392257	7.63

Source	Pr > F
RT	0.9721
CT	<.0001
RT*CT	0.0006

Contrast	DF	Contrast SS	Mean Square	F Value
Linear CT	1	1.27775817	1.27775817	103.82
LinearCT@RT1	1	0.44977126	0.44977126	36.54
LinearCT@RT2	1	0.86108817	0.86108817	69.97

Contrast	Pr > F
Linear CT	<.0001
LinearCT@RT1	<.0001
LinearCT@RT2	<.0001

Split-Split pieces: RTxCT and Linear components 39
Do we have <junk33>

Obs	_NAME_	_SOURCE_	_TYPE_	DF	SS	F	PROB
1	mc	ERROR	ERROR	282	3.47068	.	.
2	mc	RT	SS3	1	0.00002	0.001	0.97206
3	mc	CT	SS3	2	1.36183	55.326	0.00000
4	mc	RT*CT	SS3	2	0.18785	7.631	0.00059
5	mc	Linear CT	CONTRAST	1	1.27776	103.820	0.00000
6	mc	LinearCT@RT1	CONTRAST	1	0.44977	36.545	0.00000
7	mc	LinearCT@RT2	CONTRAST	1	0.86109	69.965	0.00000

Split-Split pieces: RTxCT and Linear components 40
Do we have <splitsplit3>

Obs	DF	SS	_SOURCE_
1	5	0.01875	ERRORA
2	10	0.06016	ERRORB
3	220	2.22781	ERRORC
4	282	3.47068	ERROR

5	1	0.00002	RT
6	2	1.36183	CT
7	2	0.18785	RT*CT
8	1	1.27776	Linear
9	1	0.44977	Linear
10	1	0.86109	Linear

Split-Split pieces: RT x CT and Linear contrasts 41

(RTxCT)SS = 0.1878451458

(RTxCT)MS = 0.0939225729

F(RTxCT) = 9.2750102707 p-value = 0.0001357546

(RT x LinearCT)SS = 0.0331012552

(RT x LinearCT)MS = 0.0331012552

F(RT x LinCT) = 3.2688039999 p-value = 0.0719747463

Split-Split pieces: RTxCT Quadratic components 42

The GLM Procedure

Class Level Information

Class	Levels	Values
RT	2	1 2
CT	3	1 2 3

Number of Observations Read 288
Number of Observations Used 288

Split-Split pieces: RTxCT Quadratic components 43

The GLM Procedure

Dependent Variable: mc

Source	DF	Sum of Squares	Mean Square	F Value
Model	5	1.54969428	0.30993886	25.18

Error 282 3.47068417 0.01230739

Corrected Total 287 5.02037844

Source	Pr > F
Model	<.0001
Error	
Corrected Total	

R-Square	Coeff Var	Root MSE	mc Mean
0.308681	114.8301	0.110939	0.096611

Source	DF	Type III SS	Mean Square	F Value
RT	1	0.00001513	0.00001513	0.00
CT	2	1.36183401	0.68091700	55.33
RT*CT	2	0.18784515	0.09392257	7.63

Source	Pr > F
RT	0.9721
CT	<.0001
RT*CT	0.0006

Contrast	DF	Contrast SS	Mean Square	F Value
Quadratic CT	1	0.08407584	0.08407584	6.83
QuadraticCT@RT1	1	0.00534750	0.00534750	0.43
Quadratic@RT2	1	0.23347222	0.23347222	18.97

Contrast	Pr > F
Quadratic CT	0.0094
QuadraticCT@RT1	0.5103
Quadratic@RT2	<.0001

Split-Split pieces: RTxCT Quadratic components 44
Do we have <junk34>

Obs	_NAME_	_SOURCE_	_TYPE_	DF	SS	F	PROB
1	mc	ERROR	ERROR	282	3.47068	.	.
2	mc	RT	SS3	1	0.00002	0.0012	0.97206
3	mc	CT	SS3	2	1.36183	55.3259	0.00000
4	mc	RT*CT	SS3	2	0.18785	7.6314	0.00059
5	mc	Quadratic CT	CONTRAST	1	0.08408	6.8313	0.00944
6	mc	QuadraticCT@RT1	CONTRAST	1	0.00535	0.4345	0.51033
7	mc	Quadratic@RT2	CONTRAST	1	0.23347	18.9701	0.00002

Split-Split pieces: RTxCT Quadratic components 45

Do we have <splitsplit4>

Obs	DF	SS	_SOURCE_
1	5	0.01875	ERRORA
2	10	0.06016	ERRORB
3	220	2.22781	ERRORC
4	282	3.47068	ERROR
5	1	0.00002	RT
6	2	1.36183	CT
7	2	0.18785	RT*CT
8	1	0.08408	Quadra
9	1	0.00535	Quadra
10	1	0.23347	Quadra

Split-Split pieces: RT x CT Quadratic contrasts 46

(RT x QuadraticCT)SS = 0.1547438906

(RT x QuadraticCT)MS = 0.1547438906

F(RT x QuadraticCT) = 15.281216542 p-value = 0.0001233668

Split-Split pieces: size, RT, time and Linear components 47

The GLM Procedure

Class Level Information

Class	Levels	Values
size	2	1 2
RT	2	1 2
time	2	1 2

Number of Observations Read 288
Number of Observations Used 288

Split-Split pieces: size, RT, time and Linear components 48

The GLM Procedure

Dependent Variable: mc

Source	DF	Sum of Squares	Mean Square	F Value
Model	7	0.25336983	0.03619569	2.13
Error	280	4.76700861	0.01702503	
Corrected Total	287	5.02037844		

Source	Pr > F
Model	0.0411
Error	
Corrected Total	

R-Square	Coeff Var	Root MSE	mc Mean
0.050468	135.0569	0.130480	0.096611

Source	DF	Type III SS	Mean Square	F Value
size	1	0.00880022	0.00880022	0.52
RT	1	0.00001513	0.00001513	0.00
size*RT	1	0.03087612	0.03087612	1.81
time	1	0.20693889	0.20693889	12.15
size*time	1	0.00001800	0.00001800	0.00
RT*time	1	0.00105035	0.00105035	0.06
size*RT*time	1	0.00567113	0.00567113	0.33

Source	Pr > F
size	0.4728
RT	0.9762
size*RT	0.1792

time 0.0006
size*time 0.9741
RT*time 0.8040
size*RT*time 0.5643

Split-Split pieces: size, RT, time and Linear components 49
Do we have <junk35>

Obs	_NAME_	_SOURCE_	_TYPE_	DF	SS	F	PROB
1	mc	ERROR	ERROR	280	4.76701	.	.
2	mc	size	SS3	1	0.00880	0.5169	0.47277
3	mc	RT	SS3	1	0.00002	0.0009	0.97624
4	mc	size*RT	SS3	1	0.03088	1.8136	0.17917
5	mc	time	SS3	1	0.20694	12.1550	0.00057
6	mc	size*time	SS3	1	0.00002	0.0011	0.97408
7	mc	RT*time	SS3	1	0.00105	0.0617	0.80402
8	mc	size*RT*time	SS3	1	0.00567	0.3331	0.56430

Split-Split pieces: size, RT, time and Linear components 50
Do we have <splitsplit5>

Obs	DF	SS	_SOURCE_
1	5	0.01875	ERRORA
2	10	0.06016	ERRORB
3	220	2.22781	ERRORC
4	280	4.76701	ERROR
5	1	0.00880	size
6	1	0.00002	RT
7	1	0.03088	size*R
8	1	0.20694	time
9	1	0.00002	size*t
10	1	0.00105	RT*tim
11	1	0.00567	size*R

Split-Split pieces: size, RT, time and Linear contrasts 51

(Size)SS = 0.0088002222

(Size)MS = 0.0088002222

F(Size) = 0.8690365794 p-value = 0.3522440786

(SizexRT)SS = 0.030876125

(SizexRT)MS = 0.030876125

F(SizexRT) = 3.0490686914 p-value = 0.0821792706

(SizexTime)SS = 0.000018

(SizexTime)MS = 0.000018

F(SizexTime) = 0.0017775299 p-value = 0.96640878

(SizexRTxTime)SS = 0.005671125

(SizexRTxTime)MS = 0.005671125

F(SizexRTxTime) = 0.560033025 p-value = 0.4550462068

Split-Split pieces: size CT Linear components 52

The GLM Procedure

Class Level Information

Class	Levels	Values
size	2	1 2
CT	3	1 2 3

Number of Observations Read 288
Number of Observations Used 288

Split-Split pieces: size CT Linear components 53

The GLM Procedure

Dependent Variable: mc

Source	DF	Sum of Squares	Mean Square	F Value
Model	5	1.44077865	0.28815573	22.70
Error	282	3.57959979	0.01269362	
Corrected Total	287	5.02037844		

Source	Pr > F
Model	<.0001
Error	
Corrected Total	

R-Square	Coeff Var	Root MSE	mc Mean
0.286986	116.6180	0.112666	0.096611

Source	DF	Type III SS	Mean Square	F Value
size	1	0.00880022	0.00880022	0.69
CT	2	1.36183401	0.68091700	53.64
size*CT	2	0.07014442	0.03507221	2.76

Source	Pr > F
size	0.4058
CT	<.0001
size*CT	0.0648

Contrast	DF	Contrast SS	Mean Square	F Value
Linear CT	1	1.27775817	1.27775817	100.66
LinCT@size1	1	0.76826817	0.76826817	60.52
LinCT@size2	1	0.52141276	0.52141276	41.08

Contrast	Pr > F
Linear CT	<.0001
LinCT@size1	<.0001
LinCT@size2	<.0001

Split-Split pieces: size CT Linear components 54

Do we have <junk37>

Obs	_NAME_	_SOURCE_	_TYPE_	DF	SS	F	PROB
1	mc	ERROR	ERROR	282	3.57960	.	.
2	mc	size	SS3	1	0.00880	0.693	0.40576
3	mc	CT	SS3	2	1.36183	53.642	0.00000
4	mc	size*CT	SS3	2	0.07014	2.763	0.06481

5	mc	Linear CT	CONTRAST	1	1.27776	100.661	0.00000
6	mc	LinCT@size1	CONTRAST	1	0.76827	60.524	0.00000
7	mc	LinCT@size2	CONTRAST	1	0.52141	41.077	0.00000

Split-Split pieces: size CT Linear components 55

Do we have <splitsplit7>

Obs	DF	SS	_SOURCE_
1	5	0.01875	ERRORA
2	10	0.06016	ERRORB
3	220	2.22781	ERRORC
4	282	3.57960	ERROR
5	1	0.00880	size
6	2	1.36183	CT
7	2	0.07014	size*C
8	1	1.27776	Linear
9	1	0.76827	LinCT@
10	1	0.52141	LinCT@

Split-Split pieces: size, CT Linear contrasts 56

(SizexCT)SS = 0.0701444236

(SizexCT)MS = 0.0350722118

F(SizexCT) = 3.4634392416 p-value = 0.0330401172

(Size x LinearCT)SS = 0.0119227552

(Size x LinearCT)MS = 0.0119227552

F(Size x LinearCT) = 1.1773919046 p-value = 0.2790751895

Split-Split pieces: size CT quadratic components 57

The GLM Procedure

Class Level Information

Class	Levels	Values
size	2	1 2
CT	3	1 2 3

Number of Observations Read 288
Number of Observations Used 288

Split-Split pieces: size CT quadratic components 58

The GLM Procedure

Dependent Variable: mc

Source	DF	Sum of Squares	Mean Square	F Value
Model	5	1.44077865	0.28815573	22.70
Error	282	3.57959979	0.01269362	
Corrected Total	287	5.02037844		

Source	Pr > F
Model	<.0001
Error	
Corrected Total	

R-Square	Coeff Var	Root MSE	mc Mean
0.286986	116.6180	0.112666	0.096611

Source	DF	Type III SS	Mean Square	F Value
size	1	0.00880022	0.00880022	0.69
CT	2	1.36183401	0.68091700	53.64
size*CT	2	0.07014442	0.03507221	2.76

Source	Pr > F
size	0.4058
CT	<.0001
size*CT	0.0648

Contrast	DF	Contrast SS	Mean Square	F Value
Quadratic CT	1	0.08407584	0.08407584	6.62

QuadCT@size1 1 0.00118422 0.00118422 0.09
QuadCT@size2 1 0.14111328 0.14111328 11.12

Contrast	Pr > F
Quadratic CT	0.0106
QuadCT@size1	0.7603
QuadCT@size2	0.0010

Split-Split pieces: size CT quadratic components 59
Do we have <junk38>

Obs	_NAME_	_SOURCE_	_TYPE_	DF	SS	F	PROB
1	mc	ERROR	ERROR	282	3.57960	.	.
2	mc	size	SS3	1	0.00880	0.6933	0.40576
3	mc	CT	SS3	2	1.36183	53.6425	0.00000
4	mc	size*CT	SS3	2	0.07014	2.7630	0.06481
5	mc	Quadratic CT	CONTRAST	1	0.08408	6.6235	0.01058
6	mc	QuadCT@size1	CONTRAST	1	0.00118	0.0933	0.76026
7	mc	QuadCT@size2	CONTRAST	1	0.14111	11.1169	0.00097

Split-Split pieces: size CT quadratic components 60
Do we have <splitsplit8>

Obs	DF	SS	_SOURCE_
1	5	0.01875	ERRORA
2	10	0.06016	ERRORB
3	220	2.22781	ERRORC
4	282	3.57960	ERROR
5	1	0.00880	size
6	2	1.36183	CT
7	2	0.07014	size*C
8	1	0.08408	Quadra
9	1	0.00118	QuadCT
10	1	0.14111	QuadCT

Split-Split pieces: Size CT Quadratic contrasts 61

(Size x Quad CT)SS = 0.0582216684

(Size x Quad CT)MS = 0.0582216684

F(Size x Quad CT) = 5.7494865786 p-value = 0.0173285859

Split-Split pieces: abrade CT Linear components 62

The GLM Procedure

Class Level Information

Class	Levels	Values
abrade	2	1 2
CT	3	1 2 3

Number of Observations Read 288
Number of Observations Used 288

Split-Split pieces: abrade CT Linear components 63

The GLM Procedure

Dependent Variable: mc

Source	DF	Sum of Squares	Mean Square	F Value
Model	5	1.39516374	0.27903275	21.71
Error	282	3.62521471	0.01285537	
Corrected Total	287	5.02037844		

Source	Pr > F
Model	<.0001
Error	
Corrected Total	

R-Square	Coeff Var	Root MSE	mc Mean
0.277900	117.3587	0.113382	0.096611

Source	DF	Type III SS	Mean Square	F Value
abrade	1	0.01817689	0.01817689	1.41
CT	2	1.36183401	0.68091700	52.97

abrade*CT 2 0.01515284 0.00757642 0.59

Source	Pr > F
abrade	0.2354
CT	<.0001
abrade*CT	0.5554

Contrast	DF	Contrast SS	Mean Square	F Value
Linear CT	1	1.27775817	1.27775817	99.39
LinCT@abrade1	1	0.74166504	0.74166504	57.69
LinCT@abrade2	1	0.54375651	0.54375651	42.30

Contrast	Pr > F
Linear CT	<.0001
LinCT@abrade1	<.0001
LinCT@abrade2	<.0001

Split-Split pieces: abrade CT Linear components 64
Do we have <junk39>

Obs	_NAME_	_SOURCE_	_TYPE_	DF	SS	F	PROB
1	mc	ERROR	ERROR	282	3.62521	.	.
2	mc	abrade	SS3	1	0.01818	1.4140	0.23540
3	mc	CT	SS3	2	1.36183	52.9675	0.00000
4	mc	abrade*CT	SS3	2	0.01515	0.5894	0.55536
5	mc	Linear CT	CONTRAST	1	1.27776	99.3949	0.00000
6	mc	LinCT@abrade1	CONTRAST	1	0.74167	57.6930	0.00000
7	mc	LinCT@abrade2	CONTRAST	1	0.54376	42.2980	0.00000

Split-Split pieces: abrade CT Linear components 65
Do we have <splitsplit9>

Obs	DF	SS	_SOURCE_
1	5	0.01875	ERRORA
2	10	0.06016	ERRORB
3	220	2.22781	ERRORC
4	282	3.62521	ERROR
5	1	0.01818	abrade
6	2	1.36183	CT
7	2	0.01515	abrade
8	1	1.27776	Linear

9 1 0.74167 LinCT@
10 1 0.54376 LinCT@

Split-Split pieces: Abrade, CT Linear contrasts 66

(Abrade)SS = 0.0181768889

(Abrade)MS = 0.0181768889

F(Abrade) = 1.7949980063 p-value = 0.1817006367

(AbradexCT)SS = 0.0151528403

(AbradexCT)MS = 0.0075764201

F(AbradexCT) = 0.7481840885 p-value = 0.4744252936

(Abrade x LinearCT)SS = 0.0076633802

(Abrade x LinearCT)MS = 0.0076633802

F(Abrade x LinearCT) = 0.7567715399 p-value = 0.3852889074

Split-Split pieces: Abrade CT quadratic components 67

The GLM Procedure

Class Level Information

Class	Levels	Values
abrade	2	1 2
CT	3	1 2 3

Number of Observations Read 288
Number of Observations Used 288

Split-Split pieces: Abrade CT quadratic components 68

The GLM Procedure

Dependent Variable: mc

Source	DF	Sum of Squares	Mean Square	F Value

Model	5	1.39516374	0.27903275	21.71
Error	282	3.62521471	0.01285537	
Corrected Total	287	5.02037844		

Source	Pr > F
Model	<.0001
Error	
Corrected Total	

R-Square	Coeff Var	Root MSE	mc Mean
0.277900	117.3587	0.113382	0.096611

Source	DF	Type III SS	Mean Square	F Value
abrade	1	0.01817689	0.01817689	1.41
CT	2	1.36183401	0.68091700	52.97
abrade*CT	2	0.01515284	0.00757642	0.59

Source	Pr > F
abrade	0.2354
CT	<.0001
abrade*CT	0.5554

Contrast	DF	Contrast SS	Mean Square	F Value
Quadratic CT	1	0.08407584	0.08407584	6.54
QuadCT@abrade1	1	0.07087613	0.07087613	5.51
QuadCT@abrade2	1	0.02068917	0.02068917	1.61

Contrast	Pr > F
Quadratic CT	0.0111
QuadCT@abrade1	0.0196
QuadCT@abrade2	0.2056

Split-Split pieces: Abrade CT quadratic components 69

Do we have <junk310>

Obs	_NAME_	_SOURCE_	_TYPE_	DF	SS	F	PROB
1	mc	ERROR	ERROR	282	3.62521	.	.
2	mc	abrade	SS3	1	0.01818	1.4140	0.23540
3	mc	CT	SS3	2	1.36183	52.9675	0.00000
4	mc	abrade*CT	SS3	2	0.01515	0.5894	0.55536
5	mc	Quadratic CT	CONTRAST	1	0.08408	6.5401	0.01107
6	mc	QuadCT@abrade1	CONTRAST	1	0.07088	5.5133	0.01956
7	mc	QuadCT@abrade2	CONTRAST	1	0.02069	1.6094	0.20563

Split-Split pieces: Abrade CT quadratic components 70

Do we have <splitsplit10>

Obs	DF	SS	_SOURCE_
1	5	0.01875	ERRORA
2	10	0.06016	ERRORB
3	220	2.22781	ERRORC
4	282	3.62521	ERROR
5	1	0.01818	abrade
6	2	1.36183	CT
7	2	0.01515	abrade
8	1	0.08408	Quadra
9	1	0.07088	QuadCT
10	1	0.02069	QuadCT

Split-Split pieces: abrade CT Quadratic contrasts 71

(abrade x Quad CT)SS = 0.0074894601

(abrade x Quad CT)MS = 0.0074894601

F(abrade x Quad CT) = 0.739596637 p-value = 0.3907263035

Split-Split pieces: abrade time Linear components 72

The GLM Procedure

Class Level Information

Class	Levels	Values
abrade	2	1 2
time	2	1 2

Number of Observations Read 288
Number of Observations Used 288

Split-Split pieces: abrade time Linear components 73

The GLM Procedure

Dependent Variable: mc

Source	DF	Sum of Squares	Mean Square	F Value
Model	3	0.23473000	0.07824333	4.64
Error	284	4.78564844	0.01685087	
Corrected Total	287	5.02037844		

Source	Pr > F
Model	0.0035
Error	
Corrected Total	

R-Square	Coeff Var	Root MSE	mc Mean
0.046755	134.3644	0.129811	0.096611

Source	DF	Type III SS	Mean Square	F Value
abrade	1	0.01817689	0.01817689	1.08
time	1	0.20693889	0.20693889	12.28
abrade*time	1	0.00961422	0.00961422	0.57

Source	Pr > F
abrade	0.2999
time	0.0005
abrade*time	0.4507

Split-Split pieces: abrade time Linear components 74
Do we have <junk311>

Obs	_NAME_	_SOURCE_	_TYPE_	DF	SS	F	PROB

1	mc	ERROR	ERROR	284	4.78565	.	.
2	mc	abrade	SS3	1	0.01818	1.0787	0.29987
3	mc	time	SS3	1	0.20694	12.2806	0.00053
4	mc	abrade*time	SS3	1	0.00961	0.5705	0.45067

Split-Split pieces: abrade time Linear components 75

Do we have <splitsplit11>

Obs	DF	SS	_SOURCE_
1	5	0.01875	ERRORA
2	10	0.06016	ERRORB
3	220	2.22781	ERRORC
4	284	4.78565	ERROR
5	1	0.01818	abrade
6	1	0.20694	time
7	1	0.00961	abrade

Split-Split pieces: Abrade, time 76

(AbradexTime)SS = 0.0096142222

(AbradexTime)MS = 0.0096142222

F(AbradexTime) = 0.9494204331 p-value = 0.3309370101

Split-Split pieces: not previously covered 77

The GLM Procedure

Class Level Information

Class	Levels	Values
CT	3	1 2 3
RT	2	1 2
time	2	1 2
size	2	1 2
abrade	2	1 2

Number of Observations Read 288

Number of Observations Used 288

Split-Split pieces: not previously covered 78

The GLM Procedure

Dependent Variable: mc

Source	DF	Sum of Squares	Mean Square	F Value
Model	47	2.50687944	0.05333786	5.09
Error	240	2.51349900	0.01047291	
Corrected Total	287	5.02037844		

Source	Pr > F
Model	<.0001
Error	
Corrected Total	

R-Square	Coeff Var	Root MSE	mc Mean
0.499341	105.9270	0.102337	0.096611

Source	DF	Type III SS	Mean Square	F Value
CT*RT*time	2	0.02865651	0.01432825	1.37
RT*size	1	0.03087613	0.03087613	2.95
CT*time*size	2	0.01618106	0.00809053	0.77
RT*time*size	1	0.00567112	0.00567112	0.54
CT*RT*size	2	0.00970640	0.00485320	0.46
CT*RT*time*size	2	0.00935040	0.00467520	0.45
RT*abrade	1	0.00076701	0.00076701	0.07
RT*time*abrade	1	0.04841235	0.04841235	4.62
CT*time*abrade	2	0.07568992	0.03784496	3.61

Source	Pr > F
CT*RT*time	0.2566
RT*size	0.0873
CT*time*size	0.4630

RT*time*size 0.4625
CT*RT*size 0.6297
CT*RT*time*size 0.6405
RT*abrade 0.7869
RT*time*abrade 0.0326
CT*time*abrade 0.0284

Split-Split pieces: not previously covered 79

The GLM Procedure

Dependent Variable: mc

Source	DF	Type III SS	Mean Square	F Value
CT*RT*abrade	2	0.00490942	0.00245471	0.23
CT*RT*time*abrade	2	0.08290609	0.04145305	3.96
size*abrade	1	0.00261606	0.00261606	0.25
time*size*abrade	1	0.06324939	0.06324939	6.04
RT*size*abrade	1	0.01010568	0.01010568	0.96
RT*time*size*abrade	1	0.00886668	0.00886668	0.85
CT*size*abrade	2	0.01613401	0.00806700	0.77
CT*time*size*abrade	2	0.02784284	0.01392142	1.33
CT*RT*size*abrade	2	0.04523826	0.02261913	2.16
CT*RT*time*size*abra	2	0.00815667	0.00407834	0.39

Source	Pr > F
CT*RT*abrade	0.7912
CT*RT*time*abrade	0.0204
size*abrade	0.6177
time*size*abrade	0.0147
RT*size*abrade	0.3269
RT*time*size*abrade	0.3584
CT*size*abrade	0.4640
CT*time*size*abrade	0.2666
CT*RT*size*abrade	0.1176
CT*RT*time*size*abra	0.6779

Split-Split pieces: not previously covered 80
Do we have <junk313>

Obs	_NAME_	_SOURCE_	_TYPE_	DF	SS	F	PROB
1	mc	ERROR	ERROR	240	2.51350	.	.
2	mc	CT*RT*time	SS3	2	0.02866	1.36813	0.25656

3	mc	RT*size	SS3	1	0.03088	2.94819	0.08726
4	mc	CT*time*size	SS3	2	0.01618	0.77252	0.46299
5	mc	RT*time*size	SS3	1	0.00567	0.54150	0.46253
6	mc	CT*RT*size	SS3	2	0.00971	0.46340	0.62970
7	mc	CT*RT*time*size	SS3	2	0.00935	0.44641	0.64045
8	mc	RT*abrade	SS3	1	0.00077	0.07324	0.78691
9	mc	RT*time*abrade	SS3	1	0.04841	4.62263	0.03255
10	mc	CT*time*abrade	SS3	2	0.07569	3.61360	0.02843
11	mc	CT*RT*abrade	SS3	2	0.00491	0.23439	0.79124
12	mc	CT*RT*time*abrade	SS3	2	0.08291	3.95812	0.02036
13	mc	size*abrade	SS3	1	0.00262	0.24979	0.61768
14	mc	time*size*abrade	SS3	1	0.06325	6.03933	0.01470
15	mc	RT*size*abrade	SS3	1	0.01011	0.96494	0.32694
16	mc	RT*time*size*abrade	SS3	1	0.00887	0.84663	0.35843
17	mc	CT*size*abrade	SS3	2	0.01613	0.77027	0.46403
18	mc	CT*time*size*abrade	SS3	2	0.02784	1.32928	0.26661
19	mc	CT*RT*size*abrade	SS3	2	0.04524	2.15977	0.11759
20	mc	CT*RT*time*size*abra	SS3	2	0.00816	0.38942	0.67788

Split-Split pieces: not previously covered 81

Do we have <splitsplit13>

Obs	_SOURCE_	DF	SS
1	ERROR	240	2.51350
2	CT*RT*time	2	0.02866
3	RT*size	1	0.03088
4	CT*time*size	2	0.01618
5	RT*time*size	1	0.00567
6	CT*RT*size	2	0.00971
7	CT*RT*time*size	2	0.00935
8	RT*abrade	1	0.00077
9	RT*time*abrade	1	0.04841
10	CT*time*abrade	2	0.07569
11	CT*RT*abrade	2	0.00491
12	CT*RT*time*abrade	2	0.08291
13	size*abrade	1	0.00262
14	time*size*abrade	1	0.06325
15	RT*size*abrade	1	0.01011
16	RT*time*size*abrade	1	0.00887
17	CT*size*abrade	2	0.01613
18	CT*time*size*abrade	2	0.02784
19	CT*RT*size*abrade	2	0.04524
20	CT*RT*time*size*abra	2	0.00816
21	ERRORA	5	0.01875
22	ERRORB	10	0.06016

23 ERRORC 220 2.22781

Split-Split pieces: not previously covered 82
The rest of the F and p values

Obs	_SOURCE_	DF	SS	MS	F	P
1	ERROR	240	2.51350	0.010473	1.03422	0.40028
2	**CT*RT*time**	**2**	**0.02866**	**0.014328**	**1.41494**	**0.24514**
3	**RT*size**	**1**	**0.03088**	**0.030876**	**3.04907**	**0.08218**
4	**CT*time*size**	**2**	**0.01618**	**0.008091**	**0.79895**	**0.45110**
5	**RT*time*size**	**1**	**0.00567**	**0.005671**	**0.56003**	**0.45505**
6	**CT*RT*size**	**2**	**0.00971**	**0.004853**	**0.47926**	**0.61989**
7	**CT*RT*time*size**	**2**	**0.00935**	**0.004675**	**0.46168**	**0.63083**
8	**RT*abrade**	**1**	**0.00077**	**0.000767**	**0.07574**	**0.78341**
9	**RT*time*abrade**	**1**	**0.04841**	**0.048412**	**4.78080**	**0.02983**
10	**CT*time*abrade**	**2**	**0.07569**	**0.037845**	**3.73725**	**0.02535**
11	**CT*RT*abrade**	**2**	**0.00491**	**0.002455**	**0.24241**	**0.78495**
12	**CT*RT*time*abrade**	**2**	**0.08291**	**0.041453**	**4.09356**	**0.01797**
13	**size*abrade**	**1**	**0.00262**	**0.002616**	**0.25834**	**0.61177**
14	**time*size*abrade**	**1**	**0.06325**	**0.063249**	**6.24598**	**0.01318**
15	**RT*size*abrade**	**1**	**0.01011**	**0.010106**	**0.99795**	**0.31890**
16	**RT*time*size*abrade**	**1**	**0.00887**	**0.008867**	**0.87560**	**0.35044**
17	**CT*size*abrade**	**2**	**0.01613**	**0.008067**	**0.79663**	**0.45214**
18	**CT*time*size*abrade**	**2**	**0.02784**	**0.013921**	**1.37476**	**0.25506**
19	**CT*RT*size*abrade**	**2**	**0.04524**	**0.022619**	**2.23368**	**0.10956**
20	**CT*RT*time*size*abra**	**2**	**0.00816**	**0.004078**	**0.40274**	**0.66898**
21	ERRORA	5	0.01875	0.003750	0.37031	0.86864
22	ERRORB	10	0.06016	0.006016	0.59410	0.81794
23	ERRORC	220	2.22781	0.010126	1.00000	0.50000

APPENDIX E

SPLIT-SPLIT PLOT ANOVA TABLES FOR WATER ACTIVITY AND MOISTURE CONTENT OF VACUUM BELT DRIED FROZEN BLUEBERRIES

WATER ACTIVITY ANOVA

Source	DF	SS	F	p	
Whole Plot					
Time (DT)	1	0.958	69.27	0.0004	**
Rep	5	0.828	11.97	0.008	**
Error a	5	0.069			
Split Plots					
RT	1	0.072	2.44	0.149	
DT*RT	1	0.001	0.05	0.829	
Error b	10	0.297			
Split-Split Plots					
CT	2	4.385	90.36	<.0001	**
Lin CT	1	4.163	171.58	<.0001	**
Quad CT	1	0.222	9.14	0.003	**
CT*DT	2	0.444	9.15	0.0002	**
DTxLinCT	1	0.427	17.61	<.0001	**
DtxQuadCT	1	0.017	0.69	0.406	
CT*RT	2	0.447	9.22	0.0001	**
RtxLinCT	1	0.012	0.48	0.491	
RtxQuadCT	1	0.436	17.97	<.0001	**
CT*RT*DT	2	0.168	3.47	0.033	*
Size	1	0.017	0.69	0.406	
Size*DT	1	0.047	1.93	0.167	
Size*RT	1	0.030	1.25	0.265	
Size*RT*DT	1	0.025	1.03	0.312	
Size*CT	2	0.209	4.30	0.015	*
SizexLinCT	1	0.022	0.91	0.340	
SizexQuadCT	1	0.187	7.69	0.006	**
Size*CT*DT	2	0.047	0.97	0.380	
Size*CT*RT	2	0.040	0.82	0.442	
Size*CT*RT*DT	2	0.064	1.33	0.267	
Abrade	1	0.022	0.92	0.337	
Abrade*DT	1	0.005	0.20	0.658	

Continued…..					
Source	DF	SS	F	p	
Abrade*RT	1	0.008	0.34	0.558	
Abrade*RT*DT	1	0.055	2.25	0.135	
Abrade*CT	2	0.137	2.83	0.061	
AbxLinCT	1	0.078	3.23	0.074	
AbxQuadCT	1	0.059	2.42	0.121	
Ab*CT*T	2	0.238	4.89	0.008	**
Ab*CT*RT	2	0.006	0.12	0.891	
Ab*CT*RT*T	2	0.147	3.02	0.051	
Ab*Size	1	0.010	0.40	0.530	
Ab*Size*T	1	0.093	3.83	0.052	
Ab*Size*RT	1	0.003	0.11	0.746	
Ab*Size*RT*T	1	0.039	1.61	0.206	
Ab*Size*CT	2	0.040	0.82	0.440	
Ab*Size*CT*T	2	0.033	0.67	0.510	
Ab*Size*CT*RT	2	0.059	1.21	0.301	
Ab*Size*CT*RT*T	2	0.006	0.11	0.892	
Error c	220	5.338			
Total	287	14.386			

Note: Error a is DT*Rep. Error b is Rep*RT+Rep*RT*DT. Error c is compiled from all interactions with Rep except for Rep*RT and Rep*RT*DT.

MOISTURE CONTENT ANOVA

Source	DF	SS	F	p	
Whole Plot					
Time	1	0.207	55.18	0.001	**
Rep	5	0.207	11.03	0.010	**
Error a	5	0.019			
Split Plots					
RT	1	0.000	0.00	0.961	
TIME*RT	1	0.001	0.17	0.685	
Error b	10	0.060			
Split-Split Plots					
CT	2	1.362	67.24	<.0001	**
Linear CT	1	1.278	126.18	<.0001	**
Quadratic CT	1	0.084	8.30	0.004	**
CT*Time	2	0.132	6.52	0.002	**
TimexLinCT	1	0.125	12.30	0.001	**
TimexQuadCT	1	0.007	0.73	0.395	
CT*RT	2	0.188	9.28	0.0001	**
RTxLinCT	1	0.033	3.27	0.072	

Continued……					
Source	DF	SS	F	p	
RTxQuadCT	1	0.155	15.28	0.0001	**
CT*RT*Time	2	0.029	1.41	0.245	
Size	1	0.009	0.87	0.352	
Size*Time	1	0.000	0.00	0.966	
Size*RT	1	0.031	3.05	0.082	
Size*RT*Time	1	0.006	0.56	0.455	
Size*CT	2	0.070	3.46	0.033	*
SizexLinCT	1	0.012	1.18	0.279	
SizexQuadCT	1	0.058	5.75	0.017	*
Size*CT*Time	2	0.016	0.80	0.451	
Size*CT*RT	2	0.010	0.48	0.620	
Size*CT*RT*Time	2	0.009	0.46	0.631	
Abrade	1	0.018	1.79	0.182	
Abrade*Time	1	0.010	0.95	0.331	
Abrade*RT	1	0.001	0.08	0.783	
Abrade*RT*Time	1	0.048	4.78	0.030	*
Abrade*CT	2	0.015	0.75	0.474	
AbxLinCT	1	0.008	0.76	0.385	
AbxQuadCT	1	0.007	0.74	0.391	
Ab*CT*T	2	0.076	3.74	0.025	*
Ab*CT*RT	2	0.005	0.24	0.785	
Ab*CT*RT*T	2	0.083	4.09	0.018	*
Ab*Size	1	0.003	0.26	0.612	
Ab*Size*T	1	0.063	6.25	0.013	*
Ab*Size*RT	1	0.010	1.00	0.319	
Ab*Size*RT*T	1	0.009	0.88	0.350	
Ab*Size*CT	2	0.016	0.80	0.452	
Ab*Size*CT*T	2	0.028	1.37	0.255	
Ab*Size*CT*RT	2	0.045	2.23	0.110	
Ab*Size*CT*RT*DT	2	0.008	0.40	0.669	
Error c	220	2.228			
Total	287	5.020			

Note: Error a is DT*Rep. Error b is Rep*RT+Rep*RT*DT. Error c is compiled from all interactions with Rep except for Rep*RT and Rep*RT*DT.

APPENDIX F

SPLIT-SPLIT PLOT SAS 9.1 PROGRAM AND OUTPUT FOR THE MEAN VALUES OF MOISTURE CONTENT OF VACUUM BELT DRIED FROZEN BLUEBERRIES

The following SAS program calculates the mean values for the moisture content of the vacuum belt dried pre-frozen blueberries. A split-split plot factorial design was implemented for determining treatment combinations and better understanding the impacts of various factors on the drying of the blueberries. Factors included blueberry size (‘large’ and ‘small’), blueberry pretreatment (mechanical abrasion, abraded, or no treatment, non-abraded), six drying temperature combinations (two radiation temperatures, RT, of 100 °C and 120 °C combined with three conduction temperatures, CT, of 90 °C, 110 °C, and 130 °C), and two time periods (90 and 105 min). The increments between temperatures (20 °C) and time (15 min) were selected to allow testing for Linear and Quadratic trends, which require even increments to be the same and at least three levels. The design was split by time and radiation temperature, hence a split-split plot. The first split, time, was due to the vacuum belt dryer being limited to one drying time period. The second split, radiation temperature, was because the dryer design had one radiation heating plate expanding over the three conduction heating plates. Thus, for each drying run, either 100 °C or 120 °C was set for the radiation heat plate. Radiation temperature and drying time were qualitative factors with two levels while conduction temperature was quantitative due to having three levels. Moisture content and water activity were measured for each dried sample combination of blueberries and means were calculated by SAS. The SAS program and output are included below for the moisture content values.

PROGRAM

```
/* Split-Split Plot Design... */

dm 'output; clear; log; clear';
options ls=72 ps=55 pageno=1 formdlim=' ';
title 'Split-Split Plot Statistical Analysis of Frozen Blueberry Final MC';
title1 'Batch Vacuum-belt Drying Analysis 21 AUG 2010';
data one;
do time=1 to 2;
        do RT=1 to 2;
                do CT=1 to 3;
                        do size=1 to 2;
                                do abrade=1 to 2;
                                        do rep=1 to 6;

input mc@@;
output;
end;
end;
end;
end;
end;
end;


cards;
0.307 0.633 0.282 0.158 0.242 0.024 0.331 0.227 0.278 0.121 0.092 0.062 0.113 0.173 0.199 0.217 0.090 0.296
0.384 0.173 0.208 0.153 0.203 0.080
0.270 0.397 0.184 0.145 0.088 0.062 0.033 0.094 0.016 0.323 0.242 0.472
0.042 0.100 0.121 0.073 0.075 0.052 0.128 0.099 0.145 0.018 0.174 0.022 0.033 0.013 0.015 0.001 0.001 0.002
0.014 0.021 0.030 0.009 0.016 0.006
0.025 0.020 0.017 0.053 0.007 0.005 0.054 0.073 0.140 0.016 0.011 0.004
0.078 0.390 0.269 0.278 0.199 0.157 0.515 0.566 0.557 0.200 0.087 0.188
0.405 0.260 0.004 0.287 0.033 0.205 0.380 0.562 0.567 0.166 0.134 0.281
0.057 0.029 0.033 0.014 0.004 0.130 0.058 0.024 0.015 0.021 0.030 0.018
0.022 0.023 0.019 0.075 0.045 0.070 0.016 0.218 0.083 0.013 0.016 0.013
0.013 0.007 0.014 0.017 0.016 0.020 0.009 0.016 0.006 0.008 0.000 0.015
0.121 0.006 0.011 0.017 0.014 0.021 0.007 0.013 0.003 0.145 0.212 0.240
0.210 0.088 0.066 0.127 0.108 0.044 0.182 0.069 0.127 0.068 0.014 0.253
0.089 0.103 0.142 0.127 0.175 0.030 0.047 0.021 0.234 0.057 0.093 0.185
0.016 0.075 0.041 0.111 0.001 0.130 0.260 0.350 0.268 0.000 0.000 0.000
0.009 0.026 0.014 0.007 0.011 0.012 0.019 0.025 0.013 0.022 0.107 0.148
0.012 0.007 0.013 0.004 0.006 0.003 0.030 0.007 0.017 0.009 0.060 0.063
0.008 0.006 0.009 0.010 0.011 0.099 0.114 0.018 0.022 0.007 0.005 0.008
0.192 0.219 0.238 0.074 0.012 0.015 0.044 0.707 0.125 0.015 0.022 0.034
0.672 0.137 0.669 0.227 0.064 0.101 0.040 0.024 0.032 0.027 0.072 0.031
0.018 0.026 0.014 0.009 0.008 0.041 0.226 0.144 0.149 0.011 0.009 0.042
0.000 0.000 0.000 0.027 0.009 0.015 0.015 0.000 0.036 0.015 0.035 0.020
0.012 0.008 0.008 0.003 0.009 0.015 0.013 0.023 0.029 0.027 0.013 0.013
0.011 0.011 0.031 0.007 0.008 0.010 0.020 0.053 0.170 0.007 0.007 0.010
;
/*proc print; run; /*Yes by Laura 23May 2010*/
proc glm data=one outstat=junk1;
class rep abrade size CT RT time;
```

```
model mc=time|RT|CT|size|abrade|rep /ss3;
means time RT CT size abrade time*RT time*CT time*size time*abrade RT*CT RT*size RT*abrade
CT*size CT*abrade size*abrade time*RT*abrade time*CT*abrade time*RT*CT*abrade time*size*abrade;
run;
```

OUTPUT

Batch Vacuum-belt Drying Analysis 21 AUG 2010 6

The GLM Procedure

Level of time	N	mc Mean	mc Std Dev
1	144	0.12341667	0.14356420
2	144	0.06980556	0.11423545

Level of RT	N	mc Mean	mc Std Dev
1	144	0.09638194	0.10957879
2	144	0.09684028	0.15198660

Level of CT	N	mc Mean	mc Std Dev
1	96	0.19027083	0.16665050
2	96	0.07244792	0.09420022
3	96	0.02711458	0.04318476

Level of size	N	mc Mean	mc Std Dev
1	144	0.10213889	0.13953978
2	144	0.09108333	0.12479844

Level of abrade	N	mc Mean	mc Std Dev
1	144	0.08866667	0.12501385
2	144	0.10455556	0.13911135

Level of RT	Level of time	N	mc Mean	mc Std Dev
1	1	72	0.12509722	0.12787187
1	2	72	0.06766667	0.07848926
2	1	72	0.12173611	0.15860235

2	2	72	0.07194444	0.14182184

Level of CT	Level of time	N	mc Mean	mc Std Dev
1	1	48	0.24612500	0.15622483
1	2	48	0.13441667	0.15923993

Level of CT	Level of time	N	mc Mean	mc Std Dev
2	1	48	0.09210417	0.10327700
2	2	48	0.05279167	0.08050372
3	1	48	0.03202083	0.05221864
3	2	48	0.02220833	0.03152099

Level of size	Level of time	N	mc Mean	mc Std Dev
1	1	72	0.12919444	0.15919345
1	2	72	0.07508333	0.11130933
2	1	72	0.11763889	0.12689125
2	2	72	0.06452778	0.11763083

Level of abrade	Level of time	N	mc Mean	mc Std Dev
1	1	72	0.10969444	0.12685421
1	2	72	0.06763889	0.12036720
2	1	72	0.13713889	0.15823323
2	2	72	0.07197222	0.10856101

Level of CT	Level of RT	N	mc Mean	mc Std Dev
1	1	48	0.16052083	0.11322130
1	2	48	0.22002083	0.20373716
2	1	48	0.10500000	0.11457229
2	2	48	0.03989583	0.05142946
3	1	48	0.02362500	0.03007057
3	2	48	0.03060417	0.05329554

Level of size	Level of RT	N	mc Mean	mc Std Dev
1	1	72	0.11226389	0.13159295

1	2	72	0.09201389	0.14728314
2	1	72	0.08050000	0.07972364
2	2	72	0.10166667	0.15743454

Level of abrade	Level of RT	N	mc Mean	mc Std Dev
1	1	72	0.09006944	0.11026541
1	2	72	0.08726389	0.13897695
2	1	72	0.10269444	0.10929256
2	2	72	0.10641667	0.16439164

Level of size	Level of CT	N	mc Mean	mc Std Dev
1	1	48	0.19362500	0.16951252
1	2	48	0.09808333	0.11822172
1	3	48	0.01470833	0.01266585
2	1	48	0.18691667	0.16546361
2	2	48	0.04681250	0.05116126
2	3	48	0.03952083	0.05739968

Level of abrade	Level of CT	N	mc Mean	mc Std Dev
1	1	48	0.19225000	0.15588601
1	2	48	0.05729167	0.07406322
1	3	48	0.01645833	0.02182908
2	1	48	0.18829167	0.17840188
2	2	48	0.08760417	0.10946052
2	3	48	0.03777083	0.05532697

Level of abrade	Level of size	N	mc Mean	mc Std Dev
1	1	72	0.09118056	0.12034110
1	2	72	0.08615278	0.13031594
2	1	72	0.11309722	0.15649733
2	2	72	0.09601389	0.11973768

Level of abrade	Level of RT	Level of time	N	mc Mean	mc Std Dev
1	1	1	36	0.12597222	0.13681196
1	1	2	36	0.05416667	0.05740309
1	2	1	36	0.09341667	0.11567698

1	2	2	36	0.08111111	0.16038076
2	1	1	36	0.12422222	0.12021032
2	1	2	36	0.08116667	0.09395272
2	2	1	36	0.15005556	0.18972912

Level of abrade	Level of RT	Level of time	N	mc Mean	mc Std Dev
2	2	2	36	0.06277778	0.12209296

Level of abrade	Level of CT	Level of time	N	mc Mean	mc Std Dev
1	1	1	24	0.22079167	0.13876755
1	1	2	24	0.16370833	0.16941343
1	2	1	24	0.08875000	0.08949581
1	2	2	24	0.02583333	0.03368094
1	3	1	24	0.01954167	0.02432029
1	3	2	24	0.01337500	0.01903729
2	1	1	24	0.27145833	0.17110739
2	1	2	24	0.10512500	0.14603314
2	2	1	24	0.09545833	0.11731599
2	2	2	24	0.07975000	0.10291924
2	3	1	24	0.04450000	0.06823234
2	3	2	24	0.03104167	0.03879543

Level of abrade	Level of CT	Level of RT	Level of time	N	mc Mean	mc Std Dev
1	1	1	1	12	0.22783333	0.15396979
1	1	1	2	12	0.10908333	0.05177479
1	1	2	1	12	0.21375000	0.12825197
1	1	2	2	12	0.21833333	0.22543305
1	2	1	1	12	0.13408333	0.10501122
1	2	1	2	12	0.03775000	0.04364136
1	2	2	1	12	0.04341667	0.03515539
1	2	2	2	12	0.01391667	0.01255141
1	3	1	1	12	0.01600000	0.01541546
1	3	1	2	12	0.01566667	0.02642428
1	3	2	1	12	0.02308333	0.03117242
1	3	2	2	12	0.01108333	0.00693421
2	1	1	1	12	0.19266667	0.10069967
2	1	1	2	12	0.11250000	0.08229492
2	1	2	1	12	0.35025000	0.19373089
2	1	2	2	12	0.09775000	0.19416213
2	2	1	1	12	0.14716667	0.13956285

2	2	1	2	12	0.10100000	0.12595237
2	2	2	1	12	0.04375000	0.05887139
2	2	2	2	12	0.05850000	0.07279048
2	3	1	1	12	0.03283333	0.03955625
2	3	1	2	12	0.03000000	0.03307017
2	3	2	1	12	0.05616667	0.08872924
2	3	2	2	12	0.03208333	0.04528788

Level of abrade	Level of size	Level of time	N	mc Mean	mc Std Dev
1	1	1	36	0.12727778	0.14828305
1	1	2	36	0.05508333	0.06862502
1	2	1	36	0.09211111	0.10009932
1	2	2	36	0.08019444	0.15606662
2	1	1	36	0.13111111	0.17150440
2	1	2	36	0.09508333	0.14000457
2	2	1	36	0.14316667	0.14595332
2	2	2	36	0.04886111	0.05663626

APPENDIX G

SPLIT PLOT SAS 9.1 PROGRAM AND OUTPUT FOR ANTIOXIDANT ANALYSIS OF VACUUM BELT DRIED FROZEN BLUEBERRIES

The following program was written to analyze the antioxidant values based on the split plot design for vacuum belt drying frozen blueberries. The results were used to create the ANOVA table in Table 3.5. Unlike the previous split-split plot SAS programs in Appendices A and C, the antioxidant analysis was a split plot design split only by time. Due to time and resource limitations along with the results from the larger split-split factorial design for vacuum belt drying frozen blueberries, the factors for antioxidant analysis were reduced to conduction temperature, CT, and drying time. Three levels for each factor were used with the same approach as the split-split plot drying design for the moisture properties. The same conduction temperatures and drying times were used since moisture property data had also been gathered for these samples. The split-split plot ANOVA results were used to narrow down the sample size to one size ('large'), one radiation temperature (100 °C), and no pretreatment (non-abraded). Thus, 'large' non-abraded berries were vacuum belt dried at RT=100 °C at six CT-drying time combinations (three conduction temperatures, 90 °C, 110 °C, and 130 °C, combined with three drying time periods (90, 105, and 120 min). The temperature (20 °C) and time (15 min) increments were designed to allow testing for Linear and Quadratic trends, which require consistent increments between the levels. '.' signify a missing value. Total monomeric anthocyanin (Y2), total phenolics content (Y3), and H-ORAC$_{FL}$ (Y1) values, fresh weight basis, were analyzed separately in one program.

PROGRAM

```
dm 'output; clear; log; clear';
options ls=72 ps=55 pageno=1 formdlim=' ';
title1 'Statistical Analysis of Frozen Blueberry Antioxidants';
title2 'Vacuum-belt Drying Analysis 22 AUG 2010';
data one;
input rep subrep time CT Y1 Y2 Y3;
output;

cards;
1 1 0 0 5837.6 205.0 563.5
1 2 0 0 5925.5 201.4 524.7
2 1 0 0 6064.6 183.7 499.1
2 2 0 0 5510.7 177.3 519.4
3 1 0 0 6033.4 184.5 .
3 2 0 0 . 186.0 .
1 1 90 90 7693.2 243.9 513.6
1 2 90 90 7225.7 246.8 536.5
2 1 90 90 7212.9 227.7 551.8
2 2 90 90 6499.4 221.7 530.3
3 1 90 90 7067.2 220.8 436.7
3 2 90 90 7030.0 213.6 424.8
1 1 90 110 6804.0 195.4 506.2
1 2 90 110 6582.6 195.7 526.2
2 1 90 110 7989.4 248.0 651.3
2 2 90 110 8297.5 246.8 663.5
3 1 90 110 7265.7 190.5 411.6
3 2 90 110 7691.8 192.4 401.0
1 1 90 130 7228.3 175.7 692.7
1 2 90 130 8926.1 178.1 721.0
2 1 90 130 5758.0 128.4 504.6
2 2 90 130 5986.8 123.0 507.0
3 1 90 130 8303.3 185.2 520.3
3 2 90 130 8420.8 191.3 524.7
1 1 105 90 8138.7 229.7 583.8
```

1 2 105 90 7714.1 227.8 581.0

2 1 105 90 7768.8 189.9 555.4

2 2 105 90 6770.3 187.0 539.8

3 1 105 90 4874.2 185.1 395.2

3 2 105 90 6546.8 184.9 398.3

1 1 105 110 8055.0 181.5 582.3

1 2 105 110 6491.2 180.2 649.1

2 1 105 110 6851.5 176.5 511.2

2 2 105 110 6252.7 161.4 524.2

3 1 105 110 7118.3 195.9 447.0

3 2 105 110 7498.1 199.0 443.3

1 1 105 130 6392.7 103.8 494.6

1 2 105 130 6206.0 102.9 472.6

2 1 105 130 6789.1 88.0 565.4

2 2 105 130 4861.4 86.0 572.2

3 1 105 130 5114.1 87.5 444.0

3 2 105 130 6964.1 91.2 446.7

1 1 120 90 4565.8 249.9 569.8

1 2 120 90 4543.4 238.5 567.7

2 1 120 90 4932.7 182.9 527.8

2 2 120 90 7227.7 185.7 526.7

3 1 120 90 5457.8 183.3 398.8

3 2 120 90 5319.9 182.2 403.7

1 1 120 110 8977.8 257.0 533.5

1 2 120 110 7669.7 261.5 547.9

2 1 120 110 . . .

2 2 120 110 . . .

3 1 120 110 . . .

3 2 120 110 . . .

1 1 120 130 8229.4 199.5 494.1

1 2 120 130 7090.8 193.5 529.6

2 1 120 130 . . .

2 2 120 130 . . .

3 1 120 130 . . .

3 2 120 130 . . .

```
;


%macro glmY(datain=,y=);
data &datain; set &datain;
proc glm /*noprint/* */;
title3 "Model: Y&y = time CT Split Plot on time";

class rep subrep time CT;

model Y&y = time time*rep rep subrep CT  subrep*CT time*subrep time*CT time*subrep*CT rep*subrep*CT(time) / ss3;

/*contrast "Control vs Rest-Time" time -3 1 1 1;

contrast "Control vs Rest-CT" CT -3 1 1 1; */

contrast "LinearCTY&y" CT 0 -1 0 1;

contrast "QuadCTY&y" CT 1 -1 -1 1;

test h=time e=rep*time;

test h=CT e=rep*subrep*CT(time);

test h=time*CT  e=rep*subrep*CT(time);

means time CT  time*CT / Duncan; /**/

run;
%mend glmY;
%glmY(datain=one, y=1);
%glmY(datain=one, y=2);
%glmY(datain=one, y=3);

quit;
```

OUTPUT

Y1 ($H\text{-}ORAC_{FL}$)

Statistical Analysis of Frozen Blueberry Antioxidants 1
Vacuum-belt Drying Analysis 22 AUG 2010
Model: Y1 = time CT Split Plot on time

The GLM Procedure

Class Level Information

Class	Levels	Values
rep	3	1 2 3
subrep	2	1 2
time	4	0 90 105 120
CT	4	0 90 110 130

Number of Observations Read 60
Number of Observations Used 51

Statistical Analysis of Frozen Blueberry Antioxidants 2
Vacuum-belt Drying Analysis 22 AUG 2010
Model: Y1 = time CT Split Plot on time

The GLM Procedure

Dependent Variable: Y1

Source	DF	Sum of Squares	Mean Square	F Value
Model	50	64299895.93	1285997.92	.
Error	0	0.00	.	
Corrected Total	50	64299895.93		

Source	Pr > F
Model	.
Error	
Corrected Total	

R-Square	Coeff Var	Root MSE	Y1 Mean
1.000000	.	.	6779.933

Source	DF	Type III SS	Mean Square	F Value
time	2	3983401.03	1991700.52	.
rep*time	6	5525902.40	920983.73	.
rep	2	2376.51	1188.26	.
subrep	1	274234.52	274234.52	.
CT	2	9222744.18	4611372.09	.
subrep*CT	2	772159.06	386079.53	.
subrep*time	2	563485.51	281742.76	.
time*CT	4	16483045.24	4120761.31	.

Source	Pr > F

time .
rep*time .
rep .
subrep .
CT .
subrep*CT .
subrep*time .
time*CT .

Statistical Analysis of Frozen Blueberry Antioxidants 3
Vacuum-belt Drying Analysis 22 AUG 2010
Model: Y1 = time CT Split Plot on time

The GLM Procedure

Dependent Variable: Y1

Source	DF	Type III SS	Mean Square	F Value
subrep*time*CT	4	2925476.23	731369.06	.
rep*subrep*CT(time)	23	21973326.01	955362.00	.

Source	Pr > F
subrep*time*CT	.
rep*subrep*CT(time)	.

Tests of Hypotheses Using the Type III
MS for rep*time as an Error Term

Source	DF	Type III SS	Mean Square	F Value
time	2	3983401.031	1991700.515	2.16

Tests of Hypotheses Using
the Type III MS for rep*time
as an Error Term

Source	Pr > F
time	**0.1962**

Tests of Hypotheses Using the Type III MS
for rep*subrep*CT(time) as an Error Term

Source	DF	Type III SS	Mean Square	F Value
CT	2	9222744.18	4611372.09	4.83
time*CT	4	16483045.24	4120761.31	4.31

Tests of Hypotheses Using the
Type III MS for
rep*subrep*CT(time)
as an Error Term

Source	Pr > F
CT	**0.0178**
time*CT	**0.0095**

Statistical Analysis of Frozen Blueberry Antioxidants 4
Vacuum-belt Drying Analysis 22 AUG 2010
Model: Y1 = time CT Split Plot on time

The GLM Procedure

Level of time	N	Y1 Mean	Y1 Std Dev
0	5	5874.36000	222.31744
90	18	7332.37222	851.19124
105	18	6689.28333	994.89156
120	10	6401.50000	1625.65351

Level of CT	N	Y1 Mean	Y1 Std Dev
0	5	5874.36000	222.31744
90	18	6477.14444	1202.29489
110	14	7396.09286	774.72024
130	14	6876.49286	1256.66660

Level of	Level of	Y1

time	CT	N	Mean	Std Dev
0	0	5	5874.36000	222.31744
90	90	6	7121.40000	385.84494
90	110	6	7438.50000	673.87649
90	130	6	7437.21667	1334.27384
105	90	6	6968.81667	1197.41167
105	110	6	7044.46667	663.72385
105	130	6	6054.56667	873.17588
120	90	6	5341.21667	997.75085
120	110	2	8323.75000	924.96638
120	130	2	7660.10000	805.11178

Statistical Analysis of Frozen Blueberry Antioxidants 5
Vacuum-belt Drying Analysis 22 AUG 2010
Model: Y2 = time CT Split Plot on time

The GLM Procedure

Class Level Information

Class	Levels	Values
rep	3	1 2 3
subrep	2	1 2
time	4	0 90 105 120
CT	4	0 90 110 130

Number of Observations Read 60
Number of Observations Used 52

Statistical Analysis of Frozen Blueberry Antioxidants 6
Vacuum-belt Drying Analysis 22 AUG 2010
Model: Y2 = time CT Split Plot on time

The GLM Procedure

Dependent Variable: Y2 (TMA)

Source	DF	Sum of Squares	Mean Square	F Value

Model	51	102349.6400	2006.8557	.
Error	0	0.0000	.	
Corrected Total	51	102349.6400		

Source	Pr > F
Model	.
Error	
Corrected Total	

R-Square	Coeff Var	Root MSE	Y2 Mean
1.000000	.	.	187.6000

Source	DF	Type III SS	Mean Square	F Value
time	2	17416.08774	8708.04387	.
rep*time	6	3076.01597	512.66933	.
rep	2	5583.14138	2791.57069	.
subrep	1	32.80337	32.80337	.
CT	2	39986.69680	19993.34840	.
subrep*CT	2	11.11170	5.55585	.
subrep*time	2	3.70558	1.85279	.
time*CT	4	4977.16508	1244.29127	.

Source	Pr > F
time	.
rep*time	.
rep	.
subrep	.
CT	.
subrep*CT	.
subrep*time	.
time*CT	.

The GLM Procedure

Dependent Variable: Y2

Source	DF	Type III SS	Mean Square	F Value
subrep*time*CT	4	53.79783	13.44946	.
rep*subrep*CT(time)	24	11146.05444	464.41894	.

Source	Pr > F
subrep*time*CT	.
rep*subrep*CT(time)	.

Tests of Hypotheses Using the Type III MS for rep*time as an Error Term

Source	DF	Type III SS	Mean Square	F Value
time	2	17416.08774	8708.04387	16.99

Tests of Hypotheses Using the Type III MS for rep*time as an Error Term

Source	Pr > F
time	**0.0034**

Tests of Hypotheses Using the Type III MS for rep*subrep*CT(time) as an Error Term

Source	DF	Type III SS	Mean Square	F Value
CT	2	39986.69680	19993.34840	43.05
time*CT	4	4977.16508	1244.29127	2.68

Tests of Hypotheses Using the Type III MS for rep*subrep*CT(time) as an Error Term

Source	Pr > F
CT	**<.0001**
time*CT	**0.0560**

Statistical Analysis of Frozen Blueberry Antioxidants 8
Vacuum-belt Drying Analysis 22 AUG 2010
Model: Y2 = time CT Split Plot on time

The GLM Procedure

Level of time	N	Y2 Mean	Y2 Std Dev
0	6	189.650000	10.9677254
90	18	201.388889	36.8149568
105	18	158.794444	50.4827574
120	10	213.400000	33.9002458

Level of CT	N	Y2 Mean	Y2 Std Dev
0	6	189.650000	10.9677254
90	18	211.188889	25.6224141
110	14	205.842857	32.8510792
130	14	138.150000	46.0964833

Level of time	Level of CT	N	Y2 Mean	Y2 Std Dev
0	0	6	189.650000	10.9677254
90	90	6	229.083333	13.4028977
90	110	6	211.466667	27.9033809
90	130	6	163.616667	29.9262705
105	90	6	200.733333	21.7840921
105	110	6	182.416667	13.7059719
105	130	6	93.233333	8.0226346
120	90	6	203.750000	31.5610995
120	110	2	259.250000	3.1819805
120	130	2	196.500000	4.2426407

Statistical Analysis of Frozen Blueberry Antioxidants 9
Vacuum-belt Drying Analysis 22 AUG 2010
Model: Y3 = time CT Split Plot on time

The GLM Procedure

Class Level Information

Class	Levels	Values

rep	3	1 2 3
subrep	2	1 2
time	4	0 90 105 120
CT	4	0 90 110 130

Number of Observations Read 60
Number of Observations Used 50

Statistical Analysis of Frozen Blueberry Antioxidants 10
Vacuum-belt Drying Analysis 22 AUG 2010
Model: Y3 = time CT Split Plot on time

The GLM Procedure

Dependent Variable: Y3

Source	DF	Sum of Squares	Mean Square	F Value
Model	49	279689.0512	5707.9398	.
Error	0	0.0000	.	
Corrected Total	49	279689.0512		

Source	Pr > F
Model	.
Error	
Corrected Total	

R-Square	Coeff Var	Root MSE	Y3 Mean
1.000000	.	.	520.7240

Source	DF	Type III SS	Mean Square	F Value
time	2	14267.8628	7133.9314	.
rep*time	5	1468.1809	293.6362	.

rep	2	140117.3483	70058.6742	.
subrep	1	259.6388	259.6388	.
CT	2	472.9488	236.4744	.
subrep*CT	2	788.4838	394.2419	.
subrep*time	2	205.0300	102.5150	.
time*CT	4	21483.6444	5370.9111	.

Source	Pr > F
time	.
rep*time	.
rep	.
subrep	.
CT	.
subrep*CT	.
subrep*time	.
time*CT	.

Statistical Analysis of Frozen Blueberry Antioxidants 11
Vacuum-belt Drying Analysis 22 AUG 2010
Model: Y3 = time CT Split Plot on time

The GLM Procedure

Dependent Variable: Y3 (TPC)

Source	DF	Type III SS	Mean Square	F Value
subrep*time*CT	4	726.9856	181.7464	.
rep*subrep*CT(time)	23	93001.5047	4043.5437	.

Source	Pr > F
subrep*time*CT	.
rep*subrep*CT(time)	.

Tests of Hypotheses Using the Type III
MS for rep*time as an Error Term

Source	DF	Type III SS	Mean Square	F Value
time	2	14267.86279	7133.93139	24.30

Tests of Hypotheses Using
the Type III MS for rep*time
as an Error Term

Source	Pr > F
time	0.0027

Tests of Hypotheses Using the Type III MS
for rep*subrep*CT(time) as an Error Term

Source	DF	Type III SS	Mean Square	F Value
CT	2	472.94878	236.47439	0.06
time*CT	4	21483.64444	5370.91111	1.33

Tests of Hypotheses Using the
Type III MS for
rep*subrep*CT(time)
as an Error Term

Source	Pr > F
CT	**0.9433**
time*CT	**0.2894**

Statistical Analysis of Frozen Blueberry Antioxidants 12
Vacuum-belt Drying Analysis 22 AUG 2010
Model: Y3 = time CT Split Plot on time

The GLM Procedure

Level of time	N	Y3 Mean	Y3 Std Dev
0	4	526.675000	26.9152218
90	18	534.655556	93.3662442
105	18	511.450000	72.4319579
120	10	509.960000	61.2751572

Level of CT	N	Y3 Mean	Y3 Std Dev
0	4	526.675000	26.9152218
90	18	502.316667	70.5868781
110	14	528.450000	85.8390601
130	14	534.964286	81.8579408

Level of time	Level of CT	N	Y3 Mean	Y3 Std Dev
0	0	4	526.675000	26.915222
90	90	6	498.950000	54.357805
90	110	6	526.633333	112.879027
90	130	6	578.383333	100.202743
105	90	6	508.916667	88.414397
105	110	6	526.183333	79.530709
105	130	6	499.250000	56.997254
120	90	6	499.083333	78.039924
120	110	2	540.700000	10.182338
120	130	2	511.850000	25.102291

APPENDIX H

SPLIT-PLOT ANOVA TABLES FOR PHYTOCHEMICAL CONTENT IN VACUUM BELT DRIED FROZEN BLUEBERRIES

TMA

Source	DF	SS	F	p	
Whole Plots					
Time	2	3983401	2.16	0.1962	
Rep	2	2377			
Error a	6	5525902			
Split Plots					
CT	2	9222744	4.83	0.0178	**
Time x CT	4	16483045	4.31	0.0095	
Error b	23	21973326			
Total	50	64299896			

TPC

Source	DF	SS	F	p	
Whole Plots					
Time	2	17416	16.99	0.0034	**
Rep	2	5583			
Error a	6	3076			
Split Plots					
CT	2	39987	43.05	<0.0001	**
Time x CT	4	4977	2.68	0.056	
Error b	24	11146			
Total	51	102350			